NRL Memorandum Report 754

SUMMARY OF NAVY STUDY PROGRAM FOR F4H-1 WEAPON SYSTEM

(Appendix to NRL Memorandum Report 754)

VOLUME XII

Equipment Research Branch
Radar Division

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Analytical Section Technical Momorandum #401

F4H-1 Stability Derivatives (Wind and Body Axes), Dynamic Characteristics, and Basic Performance Data (Revised)

10/9/58

by

R. B. Tucker

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ABSTRACT

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Westinghouse Air Arm Division

ANTM #401

F4H-1 STABILITY DERIVATIVES (Wind and Body Axes), DYNAMIC CHARACTERISTICS, AND BASIC PERFORMANCE DATA. (Revised). 49 Pages and 10 Figures.

This report presents basic aircraft data and some of the basic performance data ~~currently available~~ (21 November 1958) for the F4H-1 interceptor. A brief description of the F4H-1 is given.

The stability derivatives of the F4H-1 are presented in both wind axes and body axes forms for maximum and cruise speed conditions of the F4H-1 at altitudes of 1,000 feet, 30,000 feet and 50,000 feet. The airplane characteristics for both the lateral and longitudinal stick fixed modes are presented. Also included are the performance functions of the lateral and longitudinal variables as influenced by δ_a, δ_r, and δ_e.

UNITERMS

1. F4H-1
2. Stability
3. Derivatives
4. Dynamic
5. Characteristics
6. Performance
7. Data

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R. B. [illegible]

The basic performance data is presented in the form of graphs. Included are graphs of maximum velocity profile, thrust curves, maximum usable lift coefficient, the drag summary of the F4H-1 versus lift coefficient, and lift curve slope variations.

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I Synopsis

This report presents basic aircraft data and some of the basic performance data which are currently available (21 November 1958) for the F4H-1 aircraft. The data presented in this report supersedes that data presented in references 1, 2, and 3. A brief description of the F4H-1 is also given.

Included as basic aircraft data are the stability derivatives of the F4H-1 in both wind axes and body axes and the airplane characteristics for both the lateral and longitudinal modes. Also given are the performance functions of the lateral and longitudinal variables as influenced by δ_a, δ_r, and δ_e.

The basic performance data contained in this report are presented in the form of graphs. Some of the data presented is not presented in the form as originally received. Where this occurs, the method used to obtain this data is given.

II Description of the F4H-1

The F4H-1 is a two-seat, high performance, all-weather fighter that is powered by two General Electric J-79-GE-2A (17K) turbo jet engines with afterburners. It is capable of attaining high supersonic speeds and high altitudes. The basic armament consists of four Sparrow III missiles. It is also capable of carrying a variety of external stores. The F4H-1 has thin, highly swept wings of low aspect ratio, and thin swept tail surfaces.

III Basic Aircraft Data

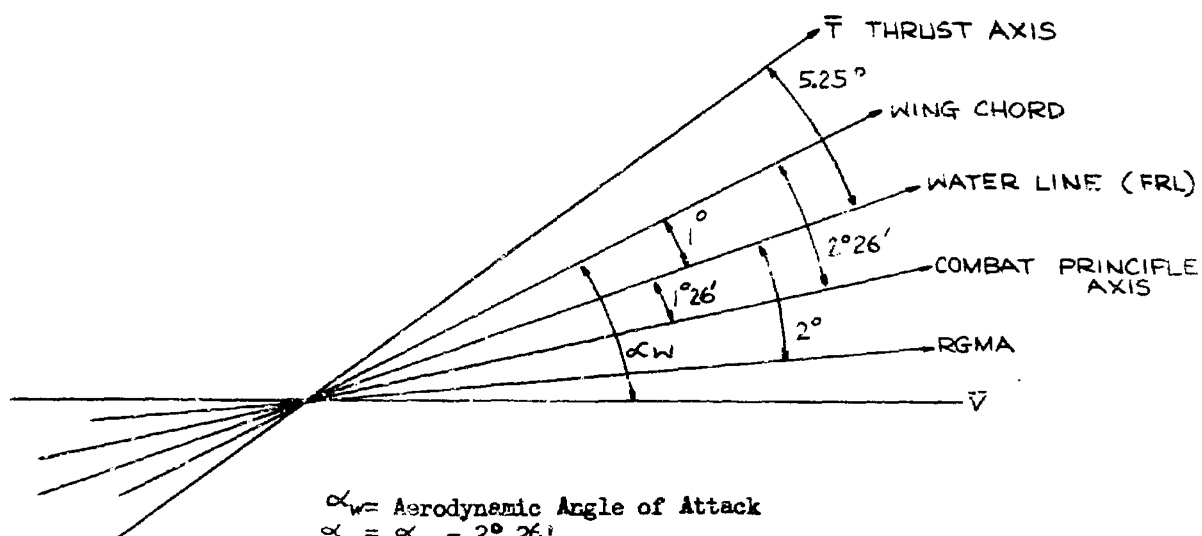
The stability derivatives are obtained for six different flight conditions. They are for both maximum speed and cruise speed of the F4H-1 at altitudes of 1,000 feet, 30,000 feet, and 50,000 feet. The velocities and altitudes used in obtaining the stability derivatives are indicated by cross marks on the F4H-1 maximum velocity profile shown in figure 2 of Appendix III.

The wind axes stability derivatives are shown in Table II and Table III for maximum and cruise velocity conditions respectively. The airplane characteristics for both the lateral and longitudinal stick-fixed modes are included in these tables. Table IV and Table V present the body axes stability derivatives for maximum and cruise speeds respectively. All the tables are contained in Appendix I. There are several coefficients for which either the data available are insufficient, or no data are available at all. These coefficients will be indicated in the table.

The pertinent angles of the F4H-1 are shown in figure 1.

In Appendix I, the force and moment equations are given from which the wind axes stability derivatives are derived. With each equation, a reference is given to show where each stability coefficient is obtained. The equations of motion in wind and body axes form are presented. The appendix also includes the stability derivatives.

Appendix 2 presents the performance functions of the lateral and longitudinal variables as influenced by δ_a, δ_r, and δ_e. The method of obtaining these performance functions is described.



α_W = Aerodynamic Angle of Attack
$\alpha_p = \alpha_w - 2° 26'$
Where α_p is angle of attack about combat principle axis line

RGMA - Radar Gimmal Mechanical Axis

Fig. 1. Pertinent Angles of F4H-1

IV Basic Performance Data

The aircraft performance data shown in this report are for the basic F4H-1 airplane carrying four Sparrow III missiles semi-submerged on the underside of the fuselage. All performance data at altitude are at combat gross weight (60 percent of take-off fuel). Wherever the engine had any effect on the data, the J-79-GE-2A(17K) engine is used.

All performance data curves are presented in Appendix III. Since some of the data shown are not in the original form as received from the manufacturer, the method used in obtaining this data is given.

Appendix I

This appendix presents the F4H-1 basic aircraft data currently available (21 November 1958). It includes the force and moment equations from which the wind axes stability derivatives are obtained. These are given in Table I. Also given in the table is a reference as to where each coefficient required by these forces and moment equations is obtained. The equations which are used to transform the wind axes stability derivatives into body axes stability derivatives are not given in this report, but are found in reference 4, pages 88 and 89 of Appendix II.

The equations of motion in both the wind axes and body axes forms are included. Tables II and III contain the wind axes stability derivatives for maximum and cruise speeds of the F4H-1 respectively. Tables IV and V give the body axes stability derivatives for the respective speed conditions previously mentioned.

Table I

CALCULATION OF STABILITY DERIVATIVES (WIND AXES)

LATERAL

Coefficient	Force and Moment Equation	Units	Reference for F4H-1 Coefficient
C_{l_β}	$L_\beta = C_{l_\beta}\, sqb$	lb.ft./rad	Ref. 6, page 9.4 Ref. 5, pages 10.10,11,12
$C_{l_{\delta a}}$	$L_{\delta a} = C_{l_{\delta a}}\, sqb$	lb.ft./rad	Ref. 5, pages 10.16, 17
$C_{l_{\delta r}}$	$L_{\delta r} = C_{l_{\delta r}}\, sqb$	lb.ft./rad	Ref. 5, pages 15.19, 20
C_{n_β}	$N_\beta = C_{n_\beta}\, sqb$	lb.ft./rad	Ref. 5, pages 11.7, 8, 9 Ref. 6, pages 10.3
$C_{n_{\delta a}}$	$N_{\delta a} = C_{n_{\delta a}}\, sqb$	lb.ft./rad	
$C_{n_{\delta r}}$	$N_{\delta r} = C_{n_{\delta r}}\, sqb$	lb.ft./rad	Ref. 5, page 11.15 Ref. 6, page 10.4
C_{y_β}	$Y_\beta = C_{y_\beta}\, sq$	lb./rad	Ref. 5, page 11.13
$C_{y_{\delta a}}$	$Y_{\delta a} = C_{y_{\delta a}}\, sq$	lb./rad	
$C_{y_{\delta r}}$	$Y_{\delta r} = C_{y_{\delta r}}\, sq$	lb./rad	Ref. 5, page 15.21
C_{l_p}	$L_p = C_{l_p}\, sqb^2/2V$	lb.ft.sec./rad	Ref. 6, page 9.11
C_{l_r}	$L_r = C_{l_r}\, sqb^2/2V$	lb.ft.sec./rad	Ref. 5, pages 15.13, 14, 15
C_{n_p}	$N_p = C_{n_p}\, sqb^2/2V$	lb.ft.sec./rad	Ref. 5, pages 15.24, 25
C_{n_r}	$N_r = C_{n_r}\, sqb^2/2V$	lb.ft.sec./rad	Ref. 5, pages 15.22
C_{y_p}	$Y_p = C_{y_p}\, sqb/2V$	lb.sec./rad	Ref. 5, pages 15.26, 27
C_{y_r}	$Y_r = C_{y_r}\, sqb/2V$	lb.sec./rad	Ref. 5, page 15.23

Table I (Continued)

LONGITUDINAL

Coefficient	Force and Moment Equation	Units	Reference for F4H-1 Coefficient
C_{m_α}	$M_\alpha = C_{m_\alpha} sq\bar{c}$	lb.ft./rad	Ref. 6, page 8.10
C_{m_u}	$M_u = C_{m_u} sq\bar{c}$	lb.ft./rad	Ref. 5, page 15.4
$C_{m_{\delta e}}$	$M_{\delta e} = C_{m_{\delta e}} sq\bar{c}$	lb.ft./rad	Ref. 5, page 9.24
C_{m_q}	$M_q = C_{m_q} sq\bar{c}^2/2V$	lb.ft.sec./rad	Ref. 5, page 15.2
$C_{m_{D\alpha}}$	$M_{\dot\alpha} = C_{m_{D\alpha}} sq\bar{c}^2/2V$	lb.ft.sec./rad	Ref. 5, page 15.8
C_{L_α}	$L_\alpha = C_{L_\alpha} sq$	lb./rad	Ref. 6, page 6.34
$C_{L_{\delta e}}$	$L_{\delta e} = C_{L_{\delta e}} sq$	lb./rad	Ref. 6, page 6.34 Ref. 5, page 9.23
C_{L_u}	$L_u = C_{L_u} sq$	lb./rad	Ref. 5, page 15.6
C_{L_q}	$L_q = C_{L_q} sq\bar{c}/2V$	lb.sec./rad	Ref. 5, page 15.10
C_{D_α}	$D_\alpha = C_{D_\alpha} sq$	lb./rad	Ref. 5, page 15.7
$C_{D_{\delta e}}$	$D_{\delta e} = C_{D_{\delta e}} sq$	lb./rad	
C_{D_y}	$D_y = C_{D_y} sq$	lb./rad	Ref. 5, page 15.3

For the F4H-1, the remaining parameters in the force and moment equations of Table I are listed below:

s - wing area	= 530 sq. ft.
b - wing span	= 38.4 ft.
$\bar{c}$ - mean aerodynamic chord	= 16.05 ft.
W - combat weight	= 39,114 lbs.

It should be pointed out that the stability derivatives obtained from the force and moment equations in Table I do not have the same value as the values given in Tables II and III. To obtain the values in Tables II and III, it is necessary to divide the above force or moment equations by its respective moment of inertia or by mV.

For the later : equation of motion, this is illustrated as follows:

Let
$$\frac{L_p}{I_x} = \ell_p$$

$$\frac{N_p}{I_z} = n_p$$

$$\frac{Y_p}{mV} = y_p$$

$$\frac{I_{xz}}{I_x} = i_{xz}$$

$$\frac{I_{xz}}{I_z} = i_{zx}$$, and so on.

Similarly for the longitudinal equations, let

$$\frac{M_\alpha}{I_y} = m_\alpha$$

$$\frac{L_q}{mV} = l_q$$

$$\frac{D_\alpha}{mV} = d_\alpha$$, and so on

In the case of wind axes, the equations of motion are first written with the stability derivatives in the form given in Table I and secondly in the form of Tables II and III where the substitutions using the above equations are used.

Given below are the equations of motion in terms of wind axes

Lateral

Roll:

$$\left(s^2 - \frac{L_p}{I_x}s\right)\phi + \left(-\frac{I_{xz}}{I_x}s^2 - \frac{L_r}{I_x}s\right)\psi - \frac{L_\beta}{I_x}\beta - \frac{L_{\delta a}\delta a}{I_x} - \frac{L_{\delta r}\delta r}{I_x} = 0$$

or

$$\left(s^2 - l_p s\right)\phi + \left(-i_{xz}s^2 - l_r s\right)\psi - l_\beta \beta - l_{\delta a}\delta a - l_{\delta r}\delta r = 0$$

Yaw

$$\left(-\frac{I_{xz}}{I_z}s^2 - \frac{N_p}{I_z}s\right)\phi + \left(s^2 - \frac{N_r}{I_z}\right)\psi - \frac{N_\beta}{I_z}\beta - \frac{N_{\delta a}}{I_z}\delta a - \frac{N_{\delta r}}{I_z}\delta r = 0$$

or

$$\left(-i_{zx}s^2 - n_p s\right)\phi + \left(s^2 - n_r s\right)\psi - n_\beta \beta - n_{\delta a}\delta a - n_{\delta r}\delta r = 0$$

Side Force:

$$\left(-\frac{Y_p}{mV}s - \frac{g}{V}\right)\phi + \left(1 - \frac{Y_r}{mV}\right)s\psi + \left(s - \frac{Y_\beta}{mV}\right)\beta - \frac{Y_{\delta a}}{mV}\delta a - \frac{Y_{\delta r}}{mV}\delta r = 0$$

or

$$\left(-y_p s - \frac{g}{V}\right)\phi + \left(1 - y_r\right)s\psi + \left(s - y_\beta\right)\beta - y_{\delta a}\delta a - y_{\delta r}\delta r = 0$$

Longitudinal

Pitch:

$$\left(s^2 - \frac{M_q + M_{\dot\alpha}}{I_y} s - \frac{M_\alpha}{I_y}\right)\alpha + \left(s^2 - \frac{M_q}{I_y} s\right)\gamma - \frac{M_u}{I_y} u - \frac{M_{\delta e}}{I_y}\delta e = 0$$

or

$$\left\{s^2 - (m_q + m_{\dot\alpha}) s - m_\alpha\right\}\alpha + \left(s^2 - m_q s\right)\gamma - m_u u - m_{\delta e}\delta e = 0$$

Lift:

$$\left(-\frac{L_q}{mV} s - \frac{L_\alpha}{mV}\right)\alpha + \left(1 - \frac{L_q}{mV}\right) s\gamma - \frac{L_u u}{mV} - \frac{L_{\delta e}}{mV}\delta e = 0$$

or

$$\left(-\ell_q s - \ell_\alpha\right)\alpha + \left(1 - \ell_q\right) s\gamma - \ell_u u - \ell_{\delta e}\delta e = 0$$

Drag:

$$\frac{D_\alpha}{mV}\alpha + \left(\frac{g}{V}\right)\gamma + \left(s + \frac{D_u}{mV}\right)u + \frac{D_{\delta e}}{mV}\delta e = 0$$

or

$$d_\alpha \alpha + \left(\frac{g}{V}\right)\gamma + \left(s + d_u\right)u + d_{\delta e}\delta e = 0$$

The six equations of motion in body axes (principal inertial axis) form are listed below:

1. $\dot u + wq - vr = X_0 + X_u(u - u_0) + X_w(w - w_0) + X_q q + X_{\delta e}\delta e + \frac{T}{M} - g\sin\theta$

2. $\dot v + ur - wp = Y_v v + Y_p p + Y_r r + Y_{\delta r}\delta r + g\sin\phi\cos\theta$

3. $\dot w + vp - uq = Z_0 + Z_u(u - u_0) + Z_w(w - w_0) + Z_q q + Z_{\delta e}\delta e + g\cos\theta\cos\phi$

4. $\dot p + \frac{I_z - I_y}{I_x} qr = \ell_v v + \ell_p p + \ell_r r + \ell_{\delta a}\delta a + \ell_{\delta r}\delta r$

5. $\dot q + \frac{I_x - I_z}{I_y} rp = m_u(u - u_0) + m_w(w - w_0) + m_{\dot w}\dot w + m_q q + m_{\delta e}\delta e$

6. $\dot r + \frac{I_y - I_x}{I_z} pq = n_v v + n_p p + n_r r + n_{\delta a}\delta a + n_{\delta r}\delta r$

Table II

F4H-1 (V_{Fmax}) Lateral Stability Derivatives - Wind Axes

Altitude - Feet	1,000	30,000	50,000
Mach No.	1.12	1.932	2.07
Velocity - Ft/sec.	1247	1923	2005
C_L	0.0377	0.0415	0.0968
q - lbs/ft^2	1795	1644	727
α_w - deg	0.592	1.22	3.12
α_p - deg	-1.84	-1.21	0.69
I_x - slug ft^2	25,198	25,135	25,101
I_y - slug ft^2	116,137	116,137	116,137
I_z - slug ft^2	133,396	133,459	133,493
I_{xz} - slug ft^2	3,479	2,289	-1,305
l_p	-2.9948	-1.5282	-0.88092
l_r	0.68511	0.43746	0.23322
l_β	-15.364	44.227	7.7368
$l_{\delta a}$ *	-75.746	-24.716	-10.252
$l_{\delta r}$	3.061	2.8749	2.0952
n_p	0.07841	0.05271	0.02454
n_r	-0.50290	-0.39293	-0.18730
n_β	21.355	15.799	8.1955
$n_{\delta a}$ **	0	0	0
$n_{\delta r}$	-2.0969	-2.0108	-1.5882
y_p	0.00034	0.000041	0.00004
y_r	0.00256	0.00104	0.00045
y_β ***	-0.39239	-0.22652	-0.09993
$y_{\delta a}$ **	0	0	0

Table II (Continued)

F4H-1 (V_{max}) Lateral Stability Derivatives - Wind Axes

Altitude - Feet	1,000	30,000	50,000
Mach No.	1.12	1.932	2.07
$y_{\delta r}$	0.00780	0.00427	0.00336
Spiral Time Constant-sec.	-356.33	-64.20	-136.57
Roll Time Constant-sec.	0.33	0.64	1.11
Dutch Roll ζ (%)	9.43	7.20	4.82
Dutch Roll ω_n (rad/sec)	4.60	4.09	2.85

Note: All coefficients given for combat weight at 60% fuel plus 4 Sparrow III missiles, c.g. 30% M.A.C. = 39,114 lbs.

*Definition of $l_{\delta a}$: Aileron defined as 1° of down going aileron yields 1.5° up going spoiler

**No data are available

***Only data available are with $\alpha_w = 0°$

Table II (Continued)

F4H-1 ($V_{F_{max}}$) Longitudinal Stability Derviatives - Wind Axes

Altitude - Feet		1,000	30,000	50,000
Velocity - Ft/sec		1247	1923	2005
m_q		-3.1297	-1.1053	-0.41683
$m_{\dot{\alpha}}$		-1.3322	-0.08793	-0.04269
m_{α}		-110.41	-75.849	-29.406
m_u		-6.5140	4.4775	2.9219
$m_{\delta e}$		-104.31	-55.141	-21.980
l_q		0.01600	0.00257	0.00096
l_{α}		2.6623	0.94669	0.37178
l_u		-0.01519	0.00492	0.01226
$l_{\delta e}$		0.36020	0.12350	0.04844
d_{α}		0.04959	0.03804	0.04014
d_u		0.06915	0.03038	0.01685
$d_{\delta e}$ **		0	0	0
Short Period	ζ (%)	32.84	12.20	7.61
	ω_n (rad/sec)	10.82	8.76	5.43
Phugoid	ζ (%)		51.34	37.08
	ω_n (rad/sec)	·	0.032	0.028
	T_1 (sec)	-25.29		
	T_2 (sec)	9.42		

Note: All coefficients given for combat weight at 60% fuel plus 4 Sparrow III missiles, c. g. 30% M.A.C. = 39,114 lbs.

*Definition of $l_{\delta a}$: Aileron defined at 1° of down going aileron yields 1.5° up going spoiler.

**No data are available.

***Only data available are with α_w = 0°.

Table III

F4H-1 ($V_{F_{cruise}}$) Lateral Stability Derivatives - Wind Axes

Altitude - feet	1,000	30,000	50,000
Mach No.	0.5	0.9	0.9
Velocity - Ft/sec.	555.5	893.7	873.0
C_L	0.204	0.205	0.519
q - lbs/ft^2	357	355	138
α_ω - deg	3.84	3.16	7.98
α_p - deg	1.41	0.73	5.55
I_x - slug ft^2	25,100	25,106	26,038
I_y - slug ft^2	116,137	116,137	116,137
I_z - slug ft^2	133,400	133,500	132,200
I_{xz} - slug ft^2	-2,660	-1,348	-10,400
l_p	-2.02	-1.369	-0.579
l_r	0.504	0.332	0.208
l_β	-14.28	-15.25	-10.85
$l_{\delta a}$ *	-15.85	-19.27	-7.21
$l_{\delta r}$	1.56	1.92	0.00646
n_p	-0.0278	-0.02215	-0.0259
n_r	-0.196	-0.1389	-0.0594
n_β	6.05	5.96	2.78
$n_{\delta a}$ **	0	0	0
$n_{\delta r}$	-3.69	-3.16	-1.418
y_p	0	0	0
y_r	0.00254	0.00110	0.00048
y_β ***	-0.1635	-0.1155	-0.0475

Table III (Continued)

F4H-1 ($V_{F_{cruise}}$) Lateral Stability Derivatives - Wind Axes

Altitude - feet	1,000	30,000	50,000
Mach No.	0.5	0.9	0.9
$y_{\delta a}$ **	0	0	0
$y_{\delta r}$	0.0302	0.0153	0.00697
Sprial Time Constant-Sec.	-930.14	1800.8	952.7
Roll Time Constant-Sec.	0.48	0.69	1.57
Dutch Roll ζ (%)	5.91	3.41	1.91
Dutch Roll ω_n (rad/sec)	2.54	2.50	1.94

Note: All coefficients given for combat weight at 60% fuel plus 4 Sparrow III missiles, c.g. 30% M.A.C. = 39,114 lbs.

*Definition of $l_{\delta a}$: Aileron defined as 1° of down going aileron yield 1.5° up going spoiler.

**No data are available.

***Only data available are with α_w = 0°.

Table III (Continued)

F4H-1 ($V_{F_{cruise}}$) Longitudinal Stability Derivatives - Wind Axes

Altitude - Feet		1,000	30,000	50,000
Velocity - Ft/sec.		555.5	893.7	873.0
m_q		-1.08	-0.785	-0.3119
$m_{\dot{\alpha}}$		-0.545	-0.417	-0.197
m_α		-4.17	-5.06	-1.96
m_u		-0.196	-3.79	-2.89
$m_{\delta e}$		-17.55	-19.28	-7.49
l_q		0.01134	0.00501	0.00204
l_α		0.937	0.709	0.282
l_u		0.1205	0.1221	0.113
$l_{\delta e}$		0.1215	0.0976	0.0387
d_α		0.0575	0.0459	0.0463
d_u		0.00389	0.0026	0.01241
$d_{\delta e}$ **		0	0	0
Short Period	ζ (%)	56.44	40.69	29.31
	ω_n (rad/sec.)	2.27	2.38	1.45
Phugoid	ζ (%)	0.55		
	ω_n(rad/sec.)	0.060		
	T_1 (sec.)		9.63	12.31
	T_2 (sec.)		-7.86	-7.79

Note: All coefficients given for combat weight at 60% fuel plus 4 Sparrow III missiles, c.g. 30% M.A.C. = 39,114 lbs.

*Definition of $l_{\delta a}$: Aileron defined as 1° of down going aileron yields 1.5° up going spoiler.

**No data are available.

***Only data available are with $\alpha_w = 0°$.

Table IV

F4H-1 ($V_{F_{max}}$) Longitudinal Stability Derivatives - Body Axes (Principal Axes)

Altitude - Feet	1,000	30,000	50,000
Mach No.	1.12	1.932	2.07
Velocity - Ft/sec	1247	1923	2005
α_w - Deg.	0.592°	1.22°	3.12°
α_p - Deg.	-1.84°	-1.21°	0.69°
γ_o - Deg.	0	0	0
D_o - lbs.	38,500	30,370	14,100
I_x - slug ft^2	25,086	25,086	25,086
I_y - slug ft^2	116,137	116,137	116,137
I_z - slug ft^2	133,508	133,508	133,508
x_u	-0.07211	-0.03134	-0.01646
x_w	-0.10778	-0.04090	-0.01973
x_q	-0.64049	-0.10424	+0.02309
$x_{\delta e}$	-14.418	-5.0134	+1.1693
m_u	-0.00806	0.00150	+0.00128
$m_{\dot{w}}$	-0.00107	-0.000045	-0.00002
m_w	-0.0383	-0.03948	-0.01464 ~~+0.01468~~
m_q	-3.1297	-1.1053	-0.41683
$m_{\delta e}$	-104.31	-55.141	-21.980
z_w	-2.6847	-0.95873	-0.37795
z_u	-0.06882	-0.02453	-0.00791
z_q	-19.943	-4.9372	-1.9176
$z_{\delta e}$	-448.94	-237.43	-97.109

Note: (1) All stability derivatives given for combat weight at 60% fuel plus 4 Sparrow III Missiles, c.g. at 30% M.A.C. = 39,114 lbs.
(2) All angles are measured in radians.
(3) All velocities are measured in ft/sec.

Table IV (Continued)

F4H-1 ($V_{F_{max}}$) Lateral Stability Derivatives - Body Axes (Principal Axes)

Altitude - Feet	1,000	30,000	50,000
Velocity - Ft/sec.	1247	1923	2005
l_v	-0.00944	+0.02396	+0.00359
l_p	-2.9724	-1.5163	-0.88585
l_r	+0.69773	+0.42618	+0.23469
$l_{\delta a}$	-76.043	-24.758	-10.257
$l_{\delta r}$	+2.7152	+2.6540	+2.1981
y_v	-0.39238	-0.22652	-0.09993
y_p	+0.52969	+0.12200	+0.06952
y_r	+3.1793	+2.0028	+0.90521
$y_{\delta a}$	0	0	0
$y_{\delta r}$	+9.7243	+8.2189	+6.7774
n_v	+0.01718	+0.00812	+0.00410
n_p	+0.08014	+0.05041	+0.02479
n_r	-0.50920	-0.39559	-0.18646
$n_{\delta a}$	+0.45889	+0.09823	-0.02321
$n_{\delta r}$	-2.1126	-2.0210	-1.5833

Note: (1) All stability derivatives given for combat weight at 60% fuel plus 4 Sparrow III missiles, c.g. at 30% M.A.C. = 39,114 lbs.

(2) All angles are measured in radians.

(3) All velocities are measured in ft/sec.

Table V

F4H-1 ($V_{F_{cruise}}$) Longitudinal Stability Derivatives - Body Axes (Principal Axes)

Altitude - Feet	1,000	30,000	50,000
Mach No.	0.5	0.9	0.9
Velocity - Ft/sec	556	894	873
α_w - Deg.	3.84	3.16	7.98
α_p - Deg.	1.41	0.73	5.55
γ_o - Deg.	0	0	0
D_o - lbs	3,688	3,815	5,147
I_x - slug ft^2	25,086	25,086	25,086
I_y - slug ft^2	116,137	116,137	116,137
I_z - slug ft^2	133,508	133,508	133,508
x_u	-0.00153	-0.00095	-0.00317
x_w	+0.0236	-0.00084	+0.01805
x_q	+0.154	+0.0565	+0.172
$x_{\delta e}$	+1.645	+1.095	+3.26
m_u	-0.00017	-0.00418	-0.00309
$m_{\dot{w}}$	-0.00098	-0.00047	-0.00022
m_w	-0.00755	-0.00574	-0.00256
m_q	-1.087	-0.784	-0.311
$m_{\delta e}$	-17.55	-19.3	-7.4935
z_w	-0.941	-0.712	-0.295
z_u	-0.0972	-0.1131	-0.0854
z_q	-6.28	-4.47	-1.77
$z_{\delta e}$	-67.2	-37.16	-33.6

Note: (1) All stability derivatives given for combat weight at 60% fuel plus 4 Sparrow III missiles, c.g. at 30% M.A.C. = 39, 114 lbs.
(2) All angles are measured in radians.
(3) All velocities are measured in ft/sec.

Table V (Continued)

F4H-1 ($V_{F_{cruise}}$) Lateral Stability Derivatives - Body Axes (Principal Axes)

Altitude - Feet	1,000	30,000	50,000
Velocity - Ft/sec	556	894	873
l_v	-0.02719	-0.018	-0.01445
l_p	-2.039	-1.365	-0.60432
l_r	+0.516	+0.3235	+0.18576
l_{δ_a}	-1[illegible].9	-19.25	-7.4273
l_{δ_r}	+2.042	+2.13	+0.72818
y_v	-0.1628	-0.115	-0.0474
y_p	-0.0345	-0.0124	-0.0402
y_r	+1.408	+0.985	+0.416
y_{δ_a}	0	0	0
y_{δ_r}	+16.75	+13.65	+6.09
n_v	+0.01081	+0.00661	+0.00291
n_p	-0.0324	-0.0221	-0.0258
n_r	-0.1945	-0.138	-0.0605
n_{δ_a}	-0.0731	-0.0457	-0.136
n_{δ_r}	-3.69	-3.15	-1.39

Note: (1) All stability derivatives given for combat weight at 60% fuel plus 4 Sparrow III missiles, c.g. at 30% M.A.C. = 39,114 lbs.

(2) All angles are measured in radians

(3) All velocities are measured in ft/sec.

Appendix II

This appendix includes the wind axes performance functions of the lateral and longitudinal variables as influenced by δ_a, δ_r, and δ_e. These quantities define the dynamic relationship of the aircraft variables, i.e.

Longitudinal:

$$\theta = \left\{ [PF]_{\alpha,\delta e} + [PF]_{\gamma,\delta e} \right\} \delta e$$

$$u = [PF]_{u,\delta e}\, \delta e$$

Lateral:

$$\beta = [PF]_{\beta,\delta r}\, \delta r + [PF]_{\beta,\delta a}\, \delta a$$

$$\psi = [PF]_{\psi,\delta r}\, \delta r + [PF]_{\psi,\delta a}\, \delta a$$

$$\phi = [PF]_{\phi,\delta r}\, \delta r + [PF]_{\phi,\delta a}\, \delta a$$

Before tabulating the values of the performance functions of the F4H-1, the method of obtaining $[PF]$ is explained.

For the longitudinal case, we refer back to the longitudinal wind axes equations of motion given in Appendix I. These three equations are written as:

$$\begin{array}{ccccc}
\alpha & \gamma & u & \delta e & \\
s^2 - (m_q + m_{\dot\alpha})s - m_\alpha & s^2 - m_q s & -m_u & -m_{\delta e} & = 0 \\
-\ell_q s - \ell_\alpha & (1-\ell_q)s & \ell_u & -\ell_{\delta e} & = 0 \\
d_\alpha & g/V & s + d_u & d_{\delta e} & = 0
\end{array}$$

For a δe input to the system, we rewrite the above as

$$\begin{array}{cccc}
\alpha & \gamma & u & \\
s^2 - (m_q + m_{\dot\alpha})s - m_\alpha & s^2 - m_q s & -m_u & = m_{\delta e}\, \delta e \\
-\ell_q s - \ell_\alpha & (1-\ell_q)s & \ell_u & = \ell_{\delta e}\, \delta e \\
d_\alpha & g/V & s + d_u & = -d_{\delta e}\, \delta e
\end{array}$$

Using Cramer's rule, we solve for an α response to a δe input. We have

$$\alpha = \frac{\begin{vmatrix} m_{\delta e}\,\delta e & s^2 - m_q s & -m_u \\ l_{\delta e}\,\delta e & (1 - l_q)s & -l_u \\ -d_{\delta e}\,\delta e & g/V & s + d_u \end{vmatrix}}{\begin{vmatrix} s^2 - (m_q + m_{\dot\alpha})s - m_\alpha & s^2 - m_q s & -m_u \\ -l_q s - l_\alpha & (1 - l_q)s & -l_u \\ d_\alpha & g/V & s + d_u \end{vmatrix}}$$

The denominator of the above is known as the stick fixed characteristic equation and is abbreviated as Δ.

The above determinant is rewritten as below:

$$\frac{\alpha}{\delta e} = \frac{\begin{vmatrix} m_{\delta e} & s^2 - m_q s & -m_u \\ l_{\delta e} & (1 - l_q)s & -l_u \\ -d_{\delta e} & g/V & s + d_u \end{vmatrix}}{\Delta}$$

where

$$[PF]_{\alpha,\delta e} = \frac{\alpha}{\delta e} = \frac{N_{\alpha,\delta e}}{\Delta}$$

Similarly, $[PF]_{\gamma,\delta e}$ and $[PF]_{u,\delta e}$ are solved for.

The lateral performance functions are derived in a similar manner, i.e.

$$\beta = \frac{\begin{vmatrix} s^2 - l_p s & -i_{xz}s^2 - l_r s & l_{\delta a}\,\delta a + l_{\delta r}\,\delta r \\ -i_{zx}s^2 - n_p s & s^2 - n_r s & n_{\delta a}\,\delta a + n_{\delta r}\,\delta r \\ -Y_p s - g/V & (1 - Y_r)s & Y_{\delta a}\,\delta a + Y_{\delta r}\,\delta r \end{vmatrix}}{\begin{vmatrix} s^2 - l_p s & -i_{xz}s^2 - l_r s & -l_\beta \\ -i_{zx}s^2 - n_p s & s^2 - n_r s & -n_\beta \\ -Y_p s - g/V & (1 - Y_r)s & s - Y_\beta \end{vmatrix}}$$

$$\beta = \frac{\delta a \begin{vmatrix} s^2 - \ell_p s & -i_{xz} s^2 - \ell_r s & \ell_{\delta a} \\ -i_{zx} s^2 - n_p s & s^2 - n_r s & n_{\delta a} \\ -Y_p s - g/V & (1 - Y_r) s & Y_{\delta a} \end{vmatrix}}{\Delta}$$

$$+ \frac{\delta r \begin{vmatrix} s^2 - \ell_p s & -i_{xz} s^2 - \ell_r s & \ell_{\delta r} \\ -i_{zx} s^2 - n_p s & s^2 - n_r s & n_{\delta r} \\ -Y_p s - g/V & (1 - Y_r) s & Y_{\delta r} \end{vmatrix}}{\Delta}$$

Hence,

$$\beta = [PF]_{\beta, \delta a} \, \delta a + [PF]_{\beta, \delta r} \, \delta r = \frac{N_{\beta, \delta a} \, \delta a}{\Delta} + \frac{N_{\beta, \delta r} \, \delta r}{\Delta}$$

The remaining lateral performance functions are obtained in the same manner.

The wind axes performance functions for the F4H-1 for the six flight conditions considered are now listed:

Case I $\quad V_F$ = 1247 fps at 1,000 feet

Longitudinal

$$\Delta = (s + 0.10620)\ (s - 0.03954)\ (s^2 + 7.1054\ s + 117.00)$$

$$N_{\alpha, \delta e} = -0.36020\ (s - 0.01205)\ (s + 0.08120)\ (s + 288.08)$$

$$N_{\gamma, \delta e} = +0.36020\ (s + 0.06997)\ (s + 25.615)\ (s - 25.788)$$

$$N_{u, \delta e} = +0.00856\ (s + 1.1963)\ (s + 600.26)$$

Lateral

$$\Delta = +0.99640\ s\ (s - 0.00281)\ (s + 3.0079)\ (s^2 + 0.86882\ s + 21.202)$$

$$N_{\phi, \delta a} = -75.746\ s\ (s^2 + 0.89529\ s + 21.498)$$

$$N_{\phi, \delta r} = 2.7714\ s\ (s^2 + 0.39453\ s + 11.965)$$

$$N_{\psi,\delta a} = -1.9755\ (s + 4.2342)\ (s^2 - 0.83532\ s + 4.9951)$$

$$N_{\psi,\delta r} = -2.0171\ (s - 0.23921)\ (s + 0.60330)\ (s + 2.9416)$$

$$N_{\beta,\delta a} = +1.9446\ s(s - 0.22411)\ (s + 2.2577)$$

$$N_{\beta,\delta r} = +0.00777\ s(s + 0.00043)(s + 3.0284)\ (s + 259.42)$$

Case II V_F = 1923 fps at 30,000 feet

<u>Longitudinal</u>

$$\Delta = (s^2 + 0.03257\ s + 0.00101)\ (s^2 + 2.1375\ s + 76.695)$$

$$N_{\alpha,\delta e} = -0.12350\ (s + 446.44)\ (s^2 + 0.03038\ s + 0.00025)$$

$$N_{\gamma,\delta e} = +0.12350\ (s + 0.02965)\ (s - 18.600)\ (s + 18.647)$$

$$N_{u,\delta e} = +0.00263\ (s + 0.34184)\ (s + 796.56)$$

<u>Lateral</u>

$$\Delta = +0.99844\ s(s - 0.01558)\ (s + 1.5657)\ (s^2 + 0.58824\ s + 16.688)$$

$$N_{\phi,\delta a} = -24.716\ s(s^2 + 0.61945\ s + 15.872)$$

$$N_{\phi,\delta r} = +2.6915\ s(s^2 + 0.39185\ s + 49.925)$$

$$N_{\psi,\delta a} = -0.42388\ (s + 4.0559)\ (s^2 - 0.75592\ s + 3.7999)$$

$$N_{\psi,\delta r} = -1.9615\ (s - 0.64503)\ (s^2 + 2.3249\ s + 1.7765)$$

$$N_{\beta,\delta a} = +0.42242\ s(s - 0.16941)\ (s + 2.2704)$$

$$N_{\beta,\delta r} = +0.00426\ s(s + 0.00141)\ (s + 1.5108)\ (s + 460.03)$$

Case III V_F = 2005 fps at 50,000 feet

<u>Longitudinal</u>

$$\Delta = (s^2 + 0.02080\ s + 0.00079)\ (s^2 + 0.82730\ s + 29.528)$$

$$N_{\alpha,\delta e} = -0.04844\ (s + 453.74)\ (s^2 + 0.01685\ s + 0.00030)$$

$$N_{\gamma,\delta e} = +0.04844\ (s + 0.01440)\ (s - 11.789)\ (s + 11.815)$$

$$N_{u,\delta e} = +0.00117\ (s + 0.12277)\ (s + 755.92)$$

Lateral

$$\Delta = +0.99949\ s(s - 0.00732)(s + 0.90465)(s^2 + 0.27492\ s + 8.1465)$$

$$N_{\phi,\delta a} = -10.252\ s(s^2 + 0.28723\ s + 8.2105)$$

$$N_{\phi,\delta r} = [illegible].778\ s[illegible]\ 0.12132\ s + 13.527)$$

$$N_{\psi,\delta a} = +0.10016\ (s - 3.5564)(s^2 + 1.1445\ s + 3.7858)$$

$$N_{\psi,\delta r} = -1.6087\ (s - 0.44053)(s^2 + 1.3612\ s + 0.66718)$$

$$N_{\beta,\delta a} = -0.10053\ s\ (s^2 - 0.86394\ s + 0.30658)$$

$$N_{\beta,\delta r} = +0.00336\ s\ (s + 0.00026)(s + 0.85914)(s + 479.04)$$

Case IV V_F = 556 fps at 1,000 feet

Longitudinal

$$\Delta = (s^2 + 0.00066\ s + 0.00360)(s^2 + 2.5590\ s + 5.1394)$$

$$N_{\alpha,\delta e} = -0.12150\ (s + 143.89)(s^2 + 0.00384\ s + 0.00695)$$

$$N_{\gamma,\delta e} = +0.12150\ (s - 0.00365)(s - 11.456)(s + 11.450)$$

$$N_{u,\delta e} = -0.000073\ (s + 0.92102)(s + 13,788)$$

Lateral

$$\Delta = +.99788\ s(s - 0.00108)(s + 2.0917)(s^2 + 0.30067\ s + 6.4809)$$

$$N_{\phi,\delta a} = -15.850\ s(s^2 + 0.35950\ s + 6.0667)$$

$$N_{\phi,\delta r} = +1.9511\ s(s + 4.3036)(s - 5.1675)$$

$$N_{\psi,\delta a} = +0.31621\ (s - 2.1497)(s^2 + 3.7067\ s + 8.1961)$$

$$N_{\psi,\delta r} = -3.7211\ (s + 2.1660)(s^2 - 0.03915\ s + 0.31180)$$

$$N_{\beta,\delta a} = -0.31540\ s(s + 0.13703)(s + 4.1762)$$

$$N_{\beta,\delta r} = +0.03014\ s(s - 0.01180)(s + 2.0576)(s + 123.35)$$

Case V V_F = 893.7 fps at 30,000 feet

Longitudinal

$$\Delta = (s + 0.10380)(s - 0.12729)(s^2 + 1.9350\ s + 5.6536)$$

$$N_{\alpha,\delta e} = -0.09760\ (s + 197.34)(s^2 + 0.00258\ s + 0.00372)$$

N_{γ,δ_e} = +0.09760 (s − 0.00431) (s − 11.510) (s + 11.729)

N_{u,δ_e} = +0.00096(s + 0.53880) (s + 922.94)

Lateral

Δ = +0.99946 s (s + 0.00056) (s + 1.4556) (s^2 + 0.17025 s + 6.2339)

N_{ϕ,δ_a} = −19.270 s(s^2 + 0.25440 s + 5.9695)

N_{ϕ,δ_r} = +2.0894 s(s + 4.0144) (s − 4.3874)

N_{ψ,δ_a} = +0.19443 (s − 2.1566) (s^2 + 4.4673 s + 9.8877)

N_{ψ,δ_r} = −3.1794 (s + 1.5566) (s^2 − 0.09651 s + 0.26804)

N_{β,δ_a} = −0.19422 s(s + 0.08744) (s + 5.6896)

N_{β,δ_r} =0.01529 s(s − 0.00633) (s + 1.4044) (s + 207.80)

Case VI V_F = 873 fps at 50,000 feet

Longitudinal

Δ = (s + 0.08125) (s − 0.12834) (s^2 + 0.85000 s + 2.1032)

N_{α,δ_e} = −0.03870 (s + 193.46) (s^2 + 0.01239 s + 0.00363)

N_{γ,δ_e} = +0.03870 (s − 0.00429) (s − 7.1886) (s + 7.3194)

N_{u,δ_e} = +0.00036 (s + 0.21721) (s + 957.31)

Lateral

Δ = +0.96868 s(s + 0.00105) (s + 0.63743) (s^2 + 0.07425 s + 3.7719)

N_{ϕ,δ_a} = −7.2100 s(s^2 + .10690 s + 2.7815)

N_{ϕ,δ_r} = +0.57224 s(s + 4.8859) (s − 5.4988)

N_{ψ,δ_a} = +0.56598 (s − 0.97662) (s^2 + 1.3540 s + 1.3381)

N_{ψ,δ_r} = −1.4185 (s + 0.99447) (s^2 − 0.38590 s + 0.40198)

N_{β,δ_a} = −0.56571 s(s + 0.03658) (s + 0.76364)

N_{β,δ_r} = +0.00675 s(s − 0.01264) (s + 0.60647) (s + 210.07)

Appendix III

This appendix presents basic performance data currently available (21 November 1958) on the F4H-1 in the forms of graphs. In some cases, it is necessary to perform calculations to obtain the curves shown. In these cases, the method used to obtain these curves is stated.

The maximum velocity envelope of the F4H-1 for different altitudes is shown in figure 2. This maximum velocity profile is given for the J79-GE-17K engines. Shown on the curve are the engine limit and the canopy structure limit. The canopy structure limit imposes a maximum velocity of Mach 2.1 on the aircraft. Indicated by cross marks on the speed profile are the aircraft velocities and altitudes at which the stability derivatives are obtained.

Figures 3(a), (b), (c) and 4(a), (b), (c) present the net thrust that is available for different altitudes over a range of various Mach numbers. These net thrust figures are for maximum power (afterburner on) and military power. The thrust curves presented in these figures are given in terms of only one engine. For interceptor velocities above Mach 1.4, the thrust varies with angle of attack at a constant altitude.

Figure 5(a), (b), (c), (d), (e), (f), (g), and (h) contains the drag summary for the F4H-1, where the lift coefficient (C_L) is plotted versus the coefficient of drag (C_D) for various Mach numbers. In some cases, these data are extended beyond that data as received from McDonnell Aircraft Co. For the method used in extending these curves, see reference 7.

In figure 6, the predicted maximum usable lift coefficient for various interceptor Mach numbers is shown. The Model F4H-1 lift curve slope variation, (C_{L_α}), versus Mach number is given in figure 7.

In figures 8, 9, and 10, the amount of thrust that is required for the aircraft to sustain different steady state load factors for various interceptor speeds is shown. Also shown is the net thrust which is available from the maximum reheat and military power settings. These thrust curves are presented in terms of two J79-GE-17K engines. The data shown in each figure are obtained for the interceptor flying at a constant altitude. These curves are obtained through use of the following 9 equations and figures 3 and 4.

1) $q = \frac{1}{2} \rho V_F^2$

2) $C_{L_1} = \dfrac{nW}{qS}$ where n = 1, 2, 3, and 4 g's

3) Obtain the value of C_{D_1} from the curve of C_L vs C_D in figure 5

4) $D_1 = C_{D_1} \, q \, S = T_1$

5) $\alpha_W = \dfrac{C_L}{C_{L_\alpha}}$

6) $L = nW - T_1 \sin(\Gamma + \alpha_w)$, where $\Gamma = 4.25°$ from Fig. 1

7) $C_{L2} = \frac{L}{q\, S}$

8) Obtain the values of C_{D_2} from the curve of C_L vs C_D in figure 5

9) $D_2 = T_2 = C_{D_2}\, q\, s$

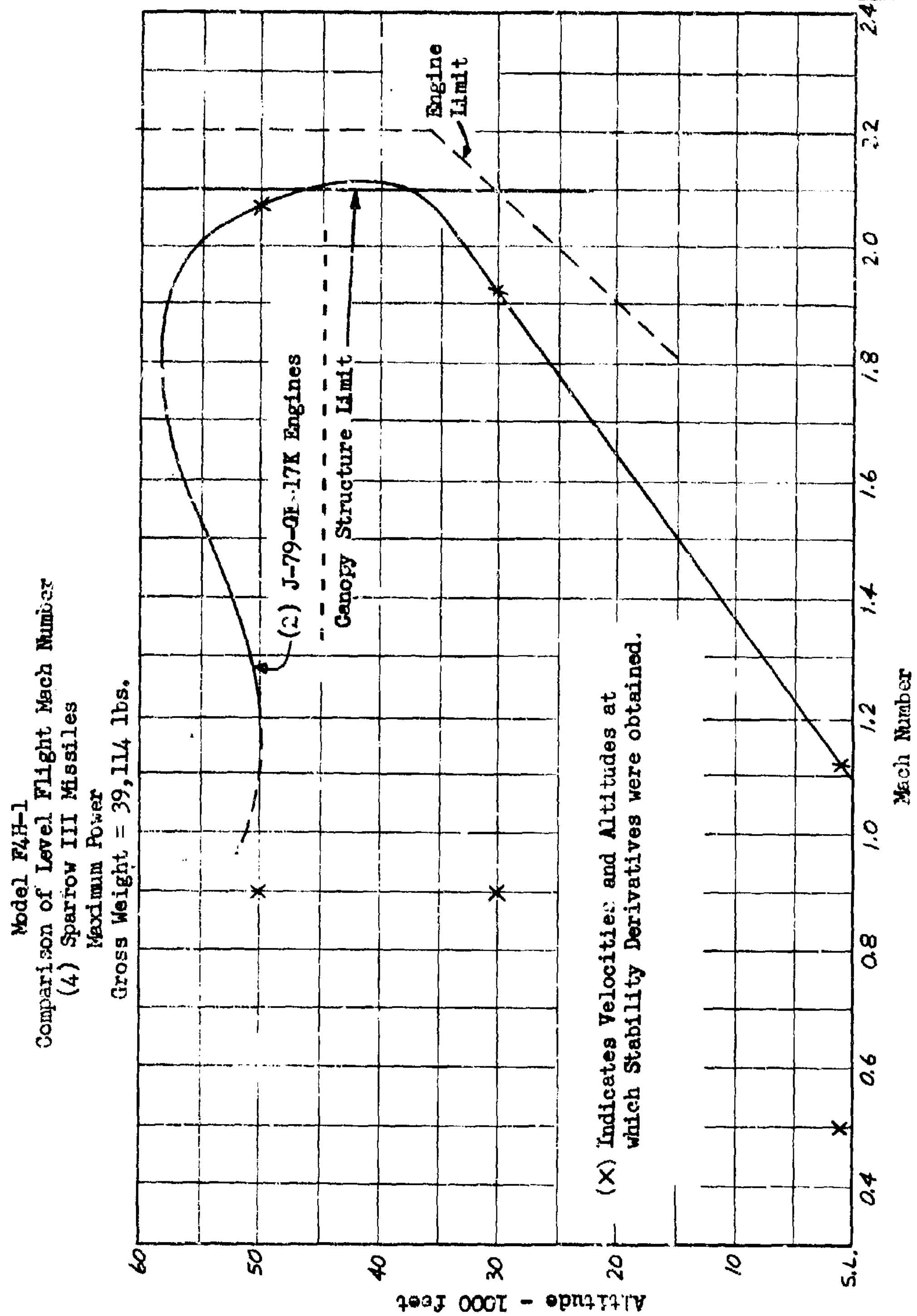


Fig. 2. F4H-1 Maximum Velocity Profile

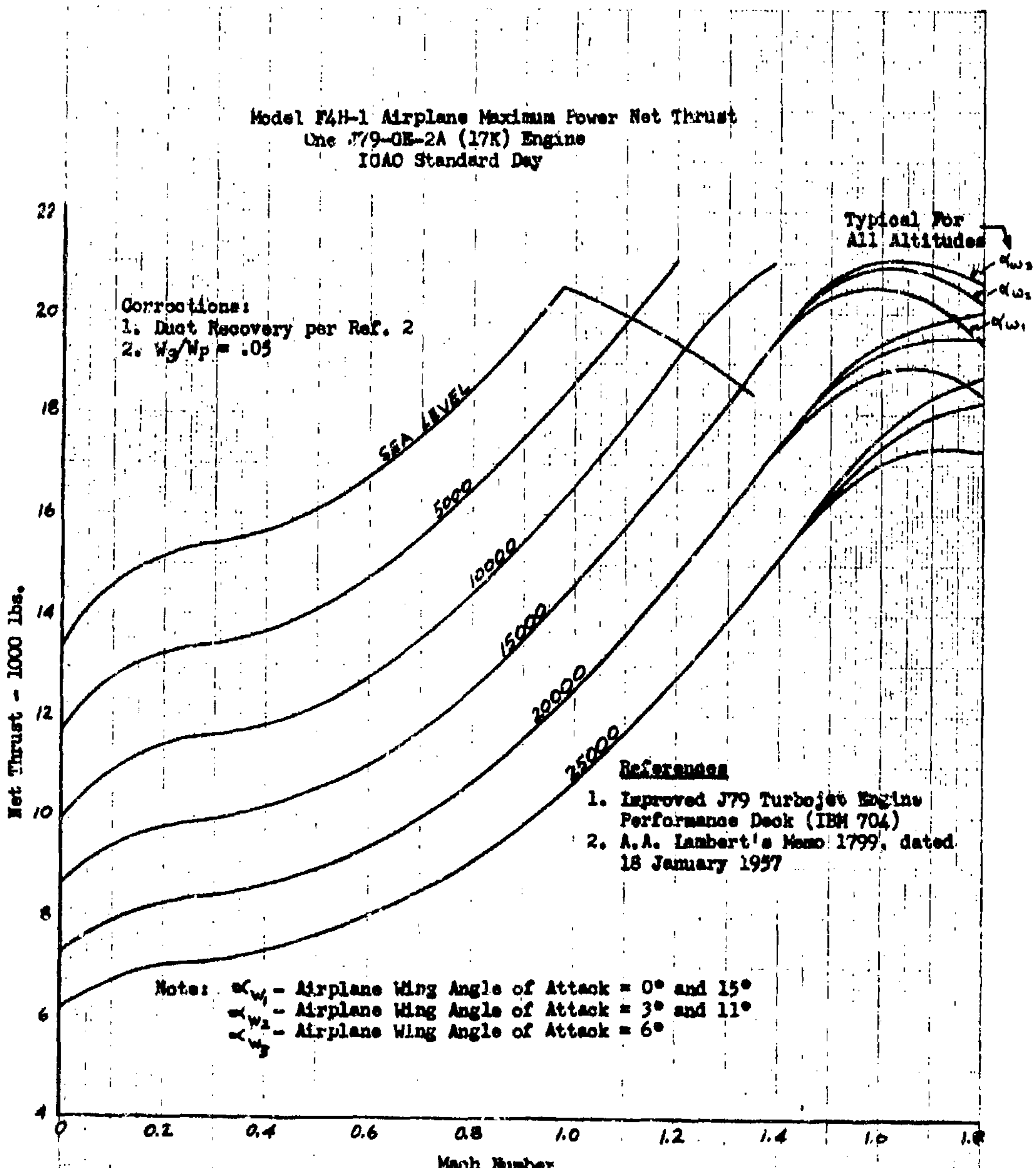


Fig. 3(a). Model F4H-1 Airplane Maximum Power Net Thrust

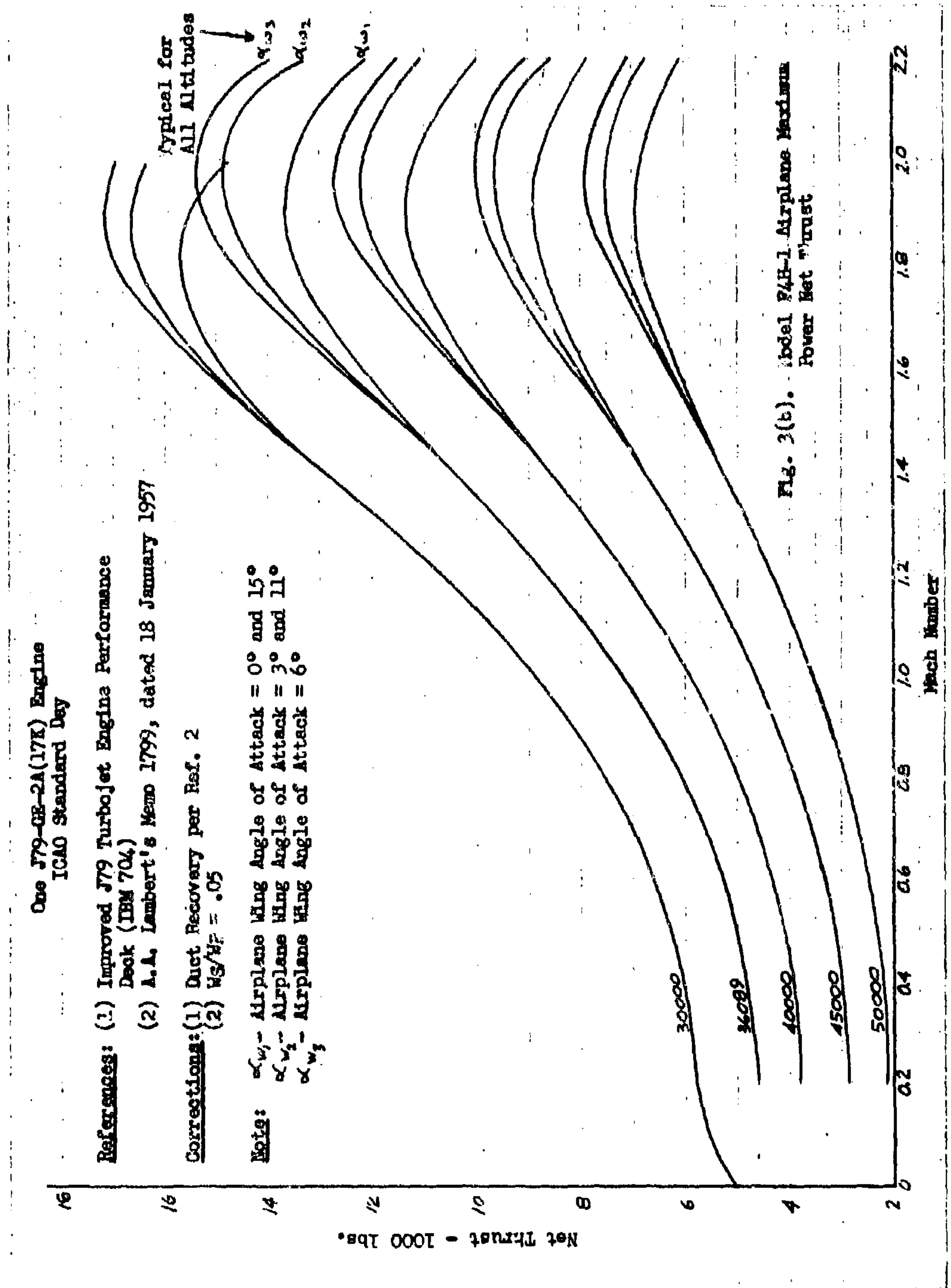


Fig. 3(b). Model F4H-1 Airplane Maximum Power Net Thrust

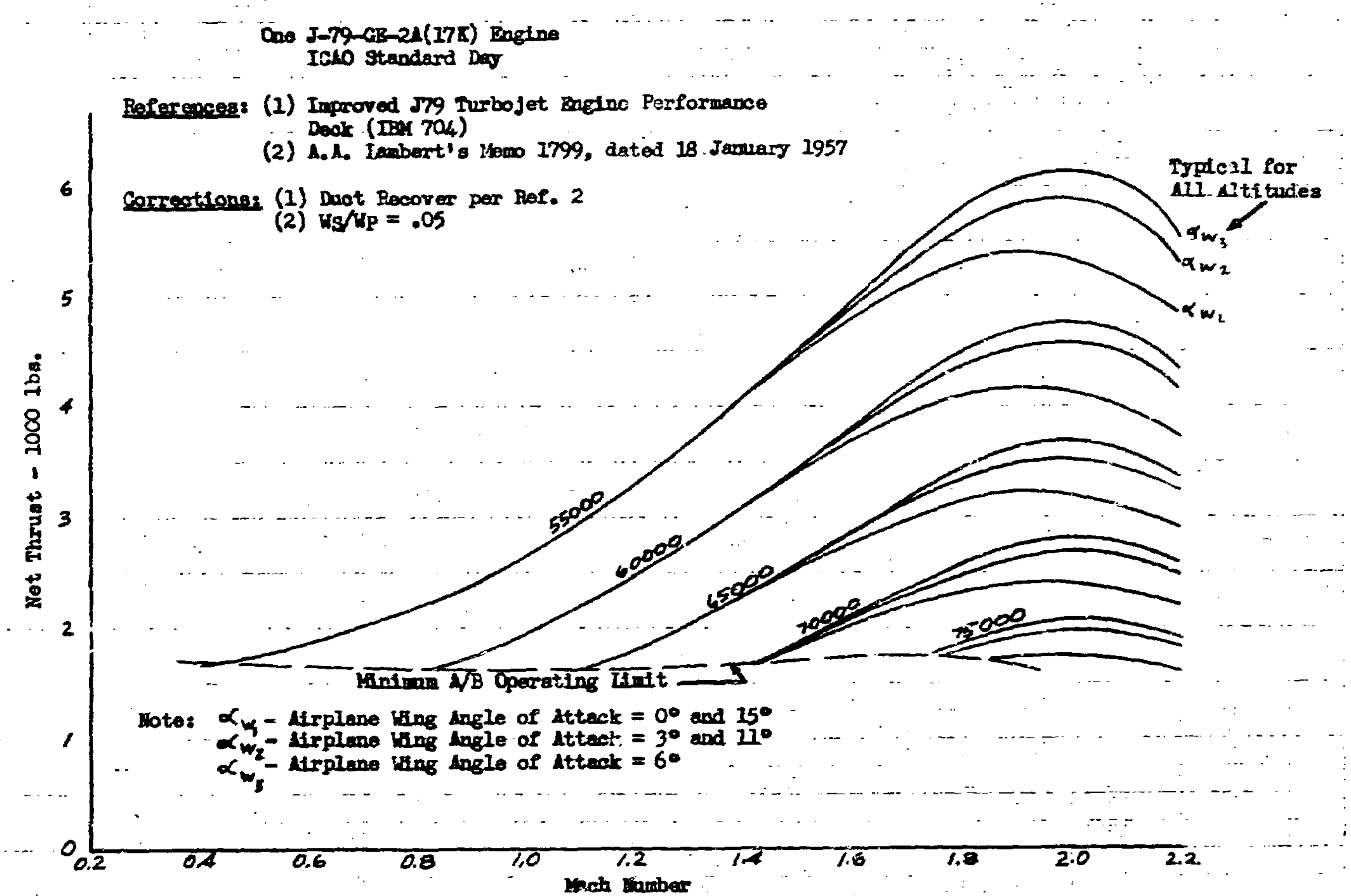


Fig. 3(c). Model F4H-1 Airplane Maximum Net Thrust

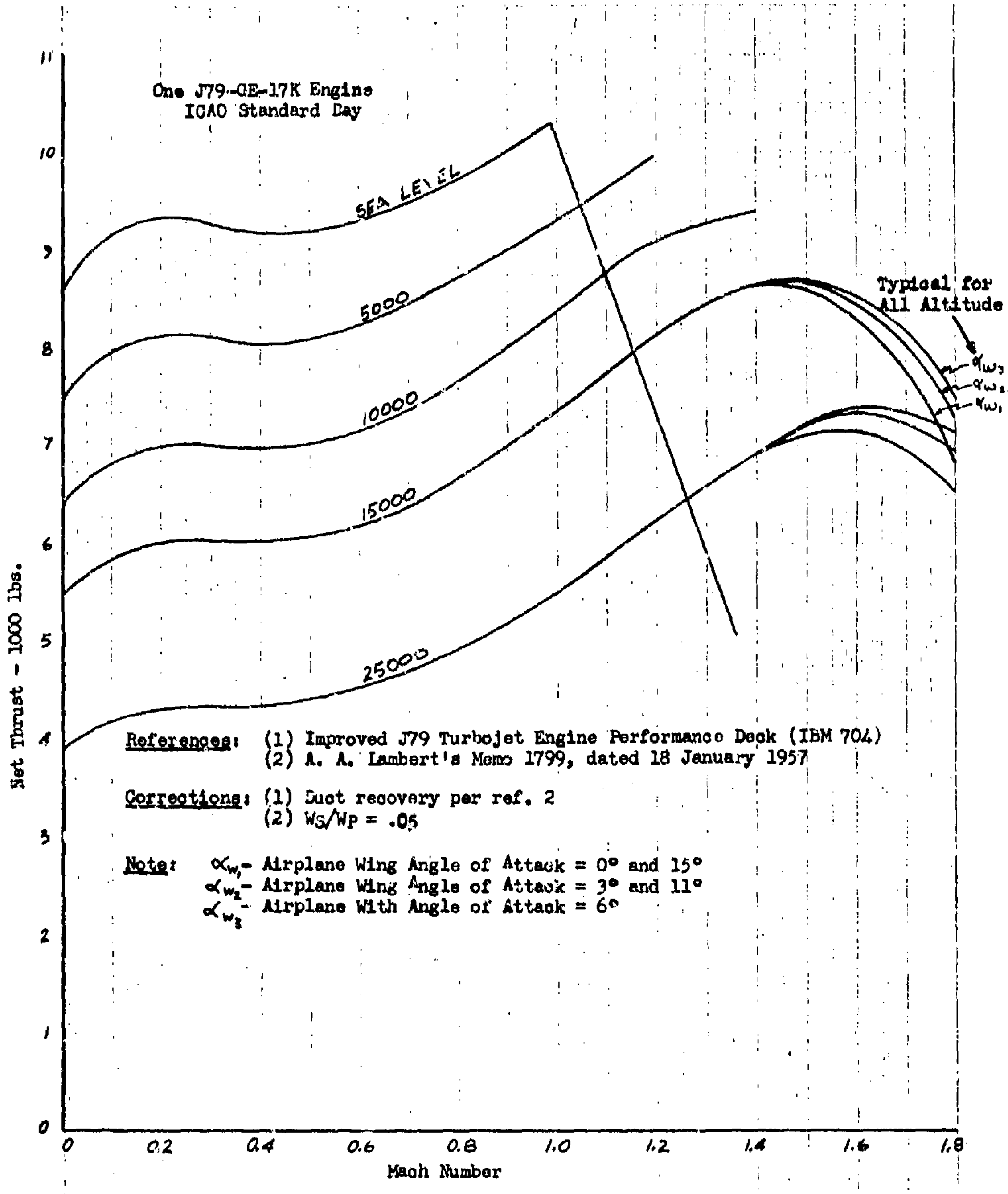


Fig. 4(a). Model F4H-1 Airplane Military Power Net Thrust

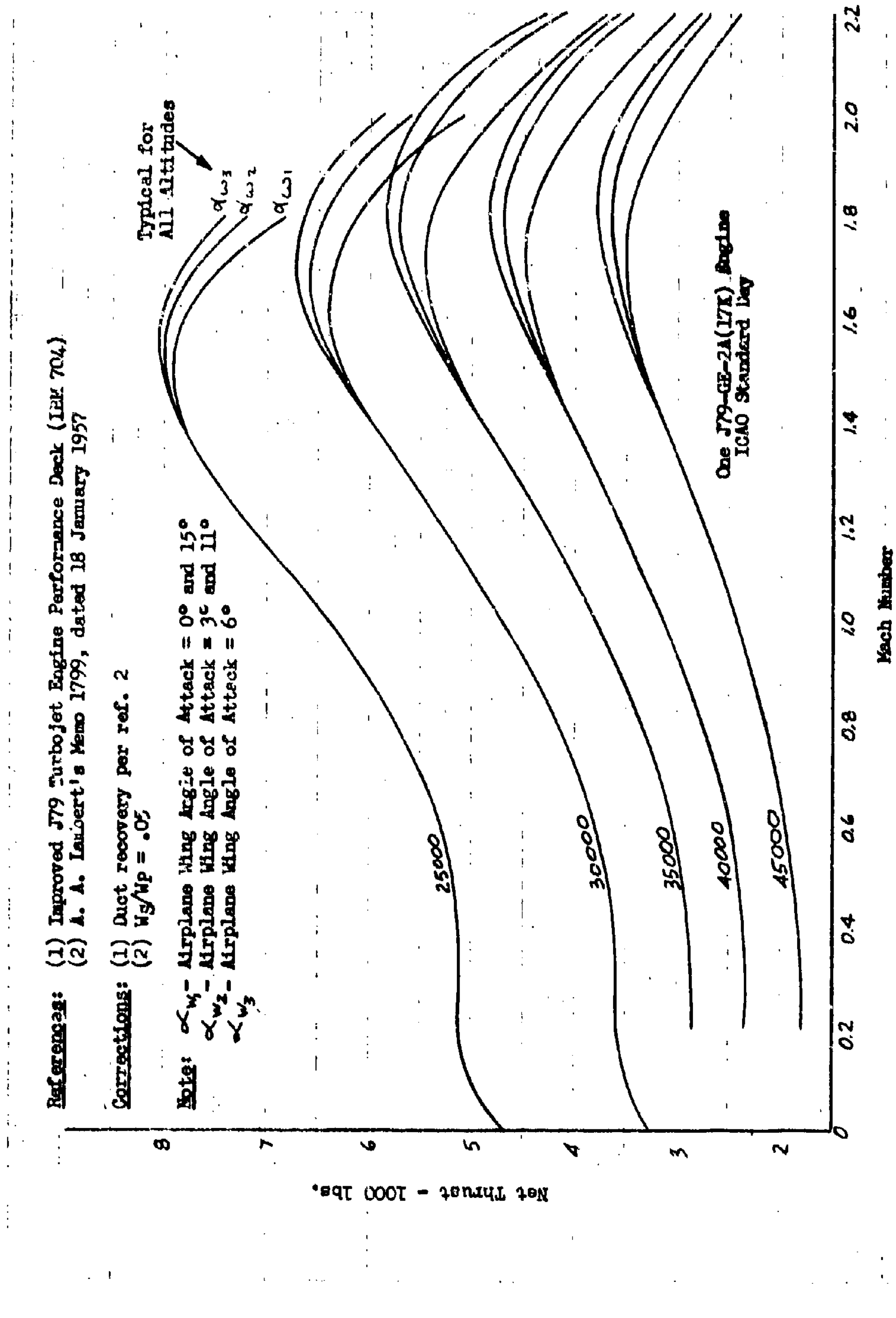


Fig. 4(b). Model F4H-1 Airplane Military Power Net Thrust

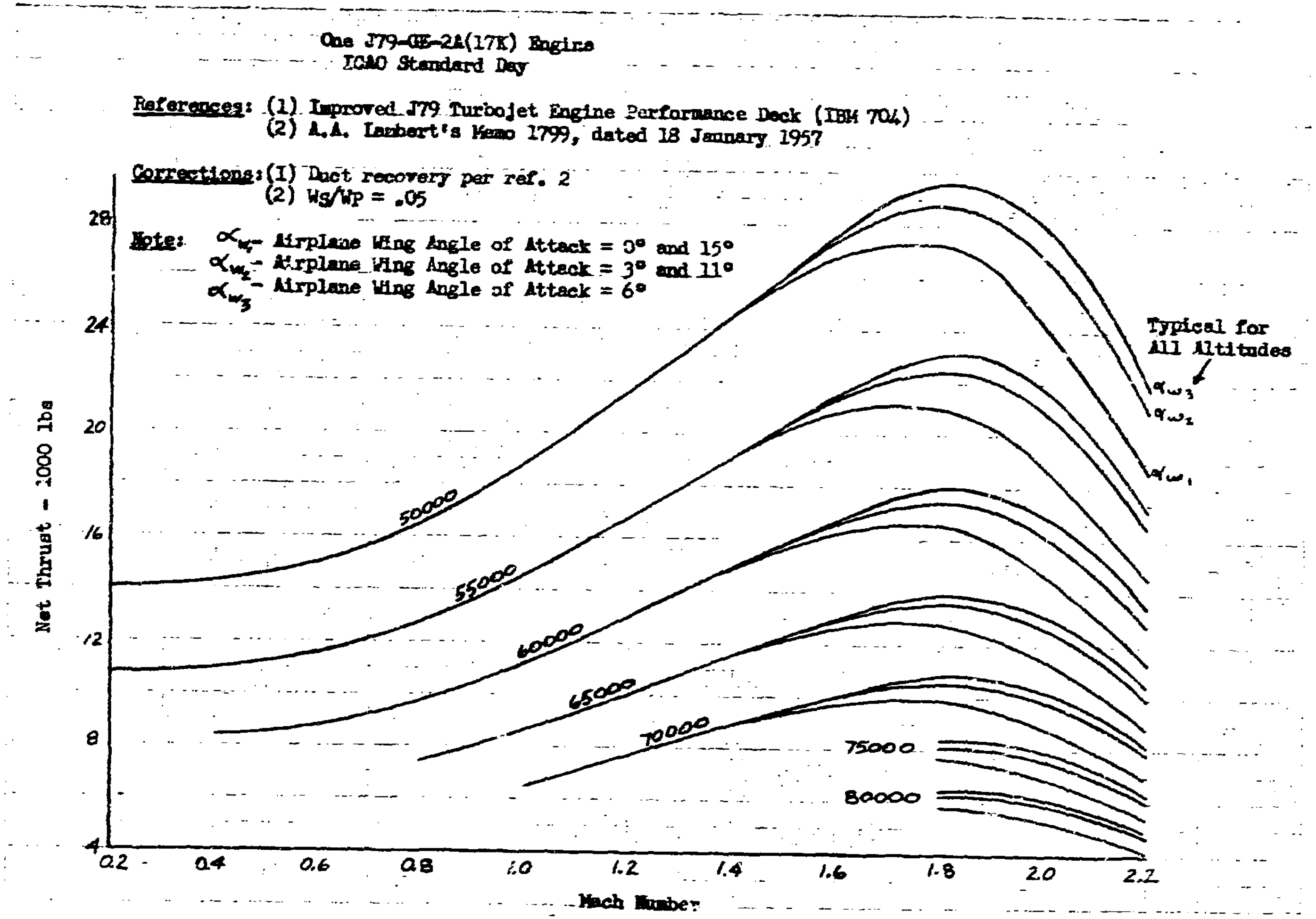


Fig. 4(c). Model F4H-1 Airplane Military Power Net Thrust

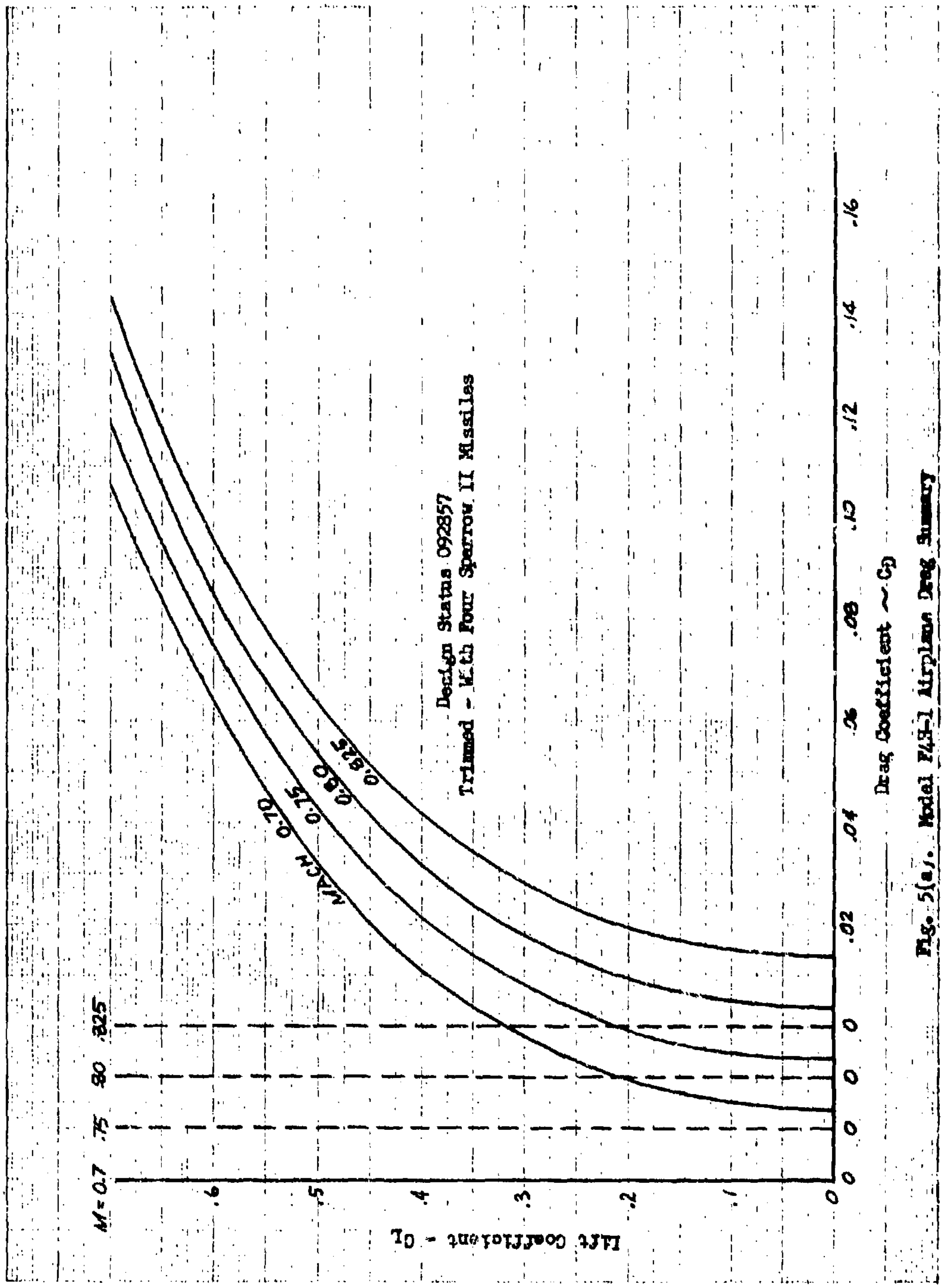


Fig. 5(a). Model F4H-1 Airplane Drag Summary

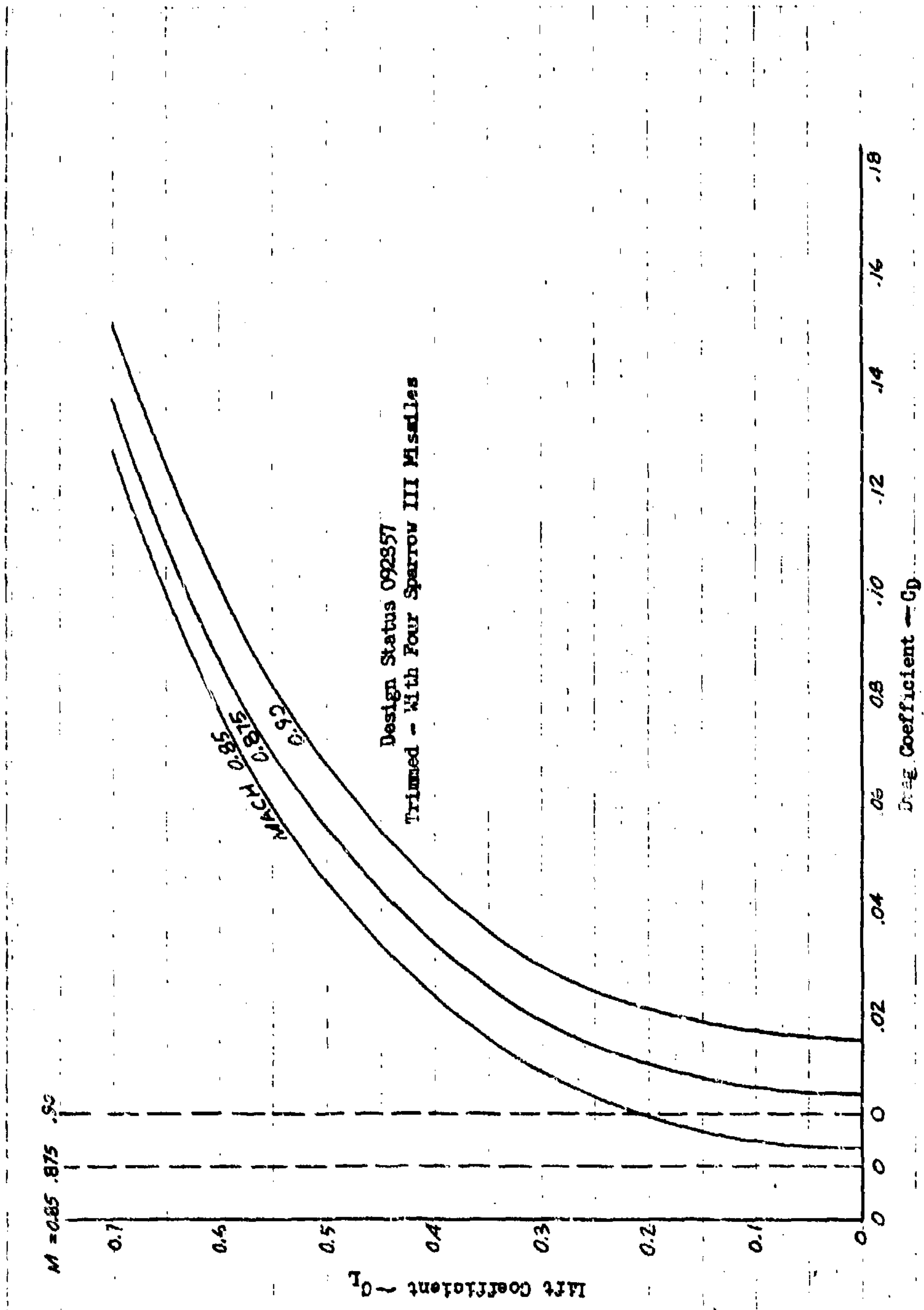


Fig. 5(b). Model F4H-1 Airplane Drag Summary

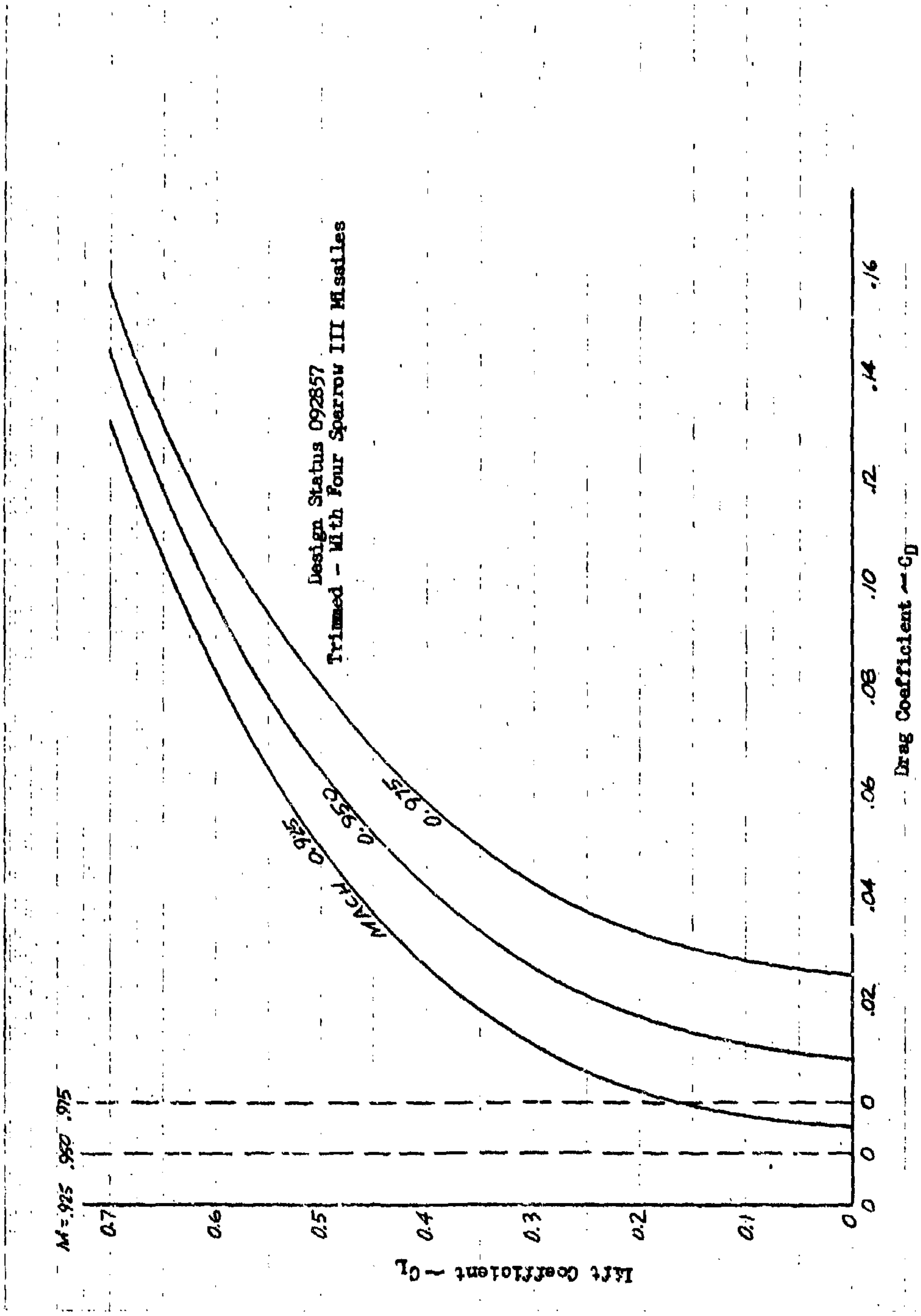


Fig. 5(c) Model F4H-1 Airplane Drag Summary

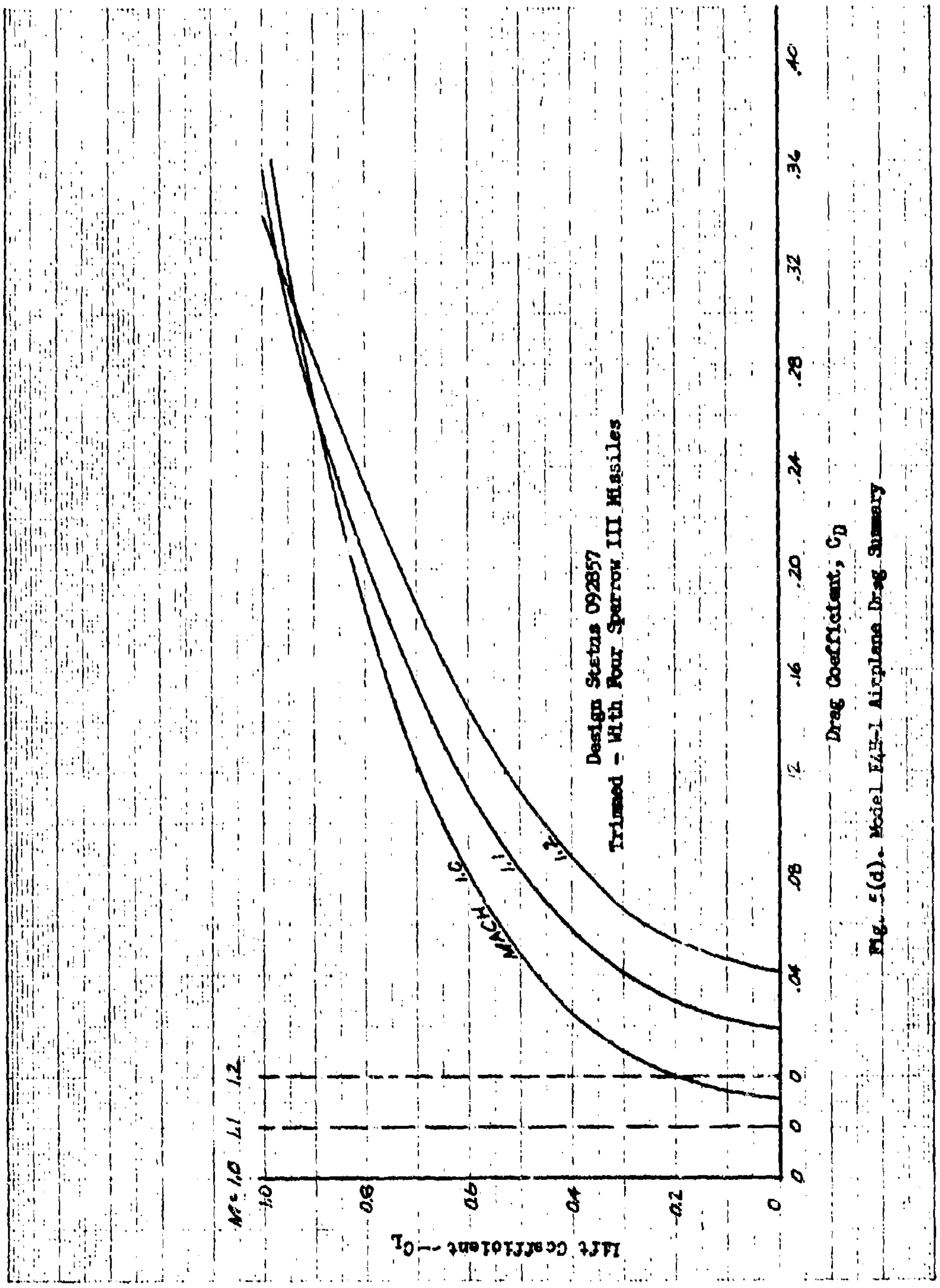


Fig. 5(d). Model F4H-1 Airplane Drag Summary

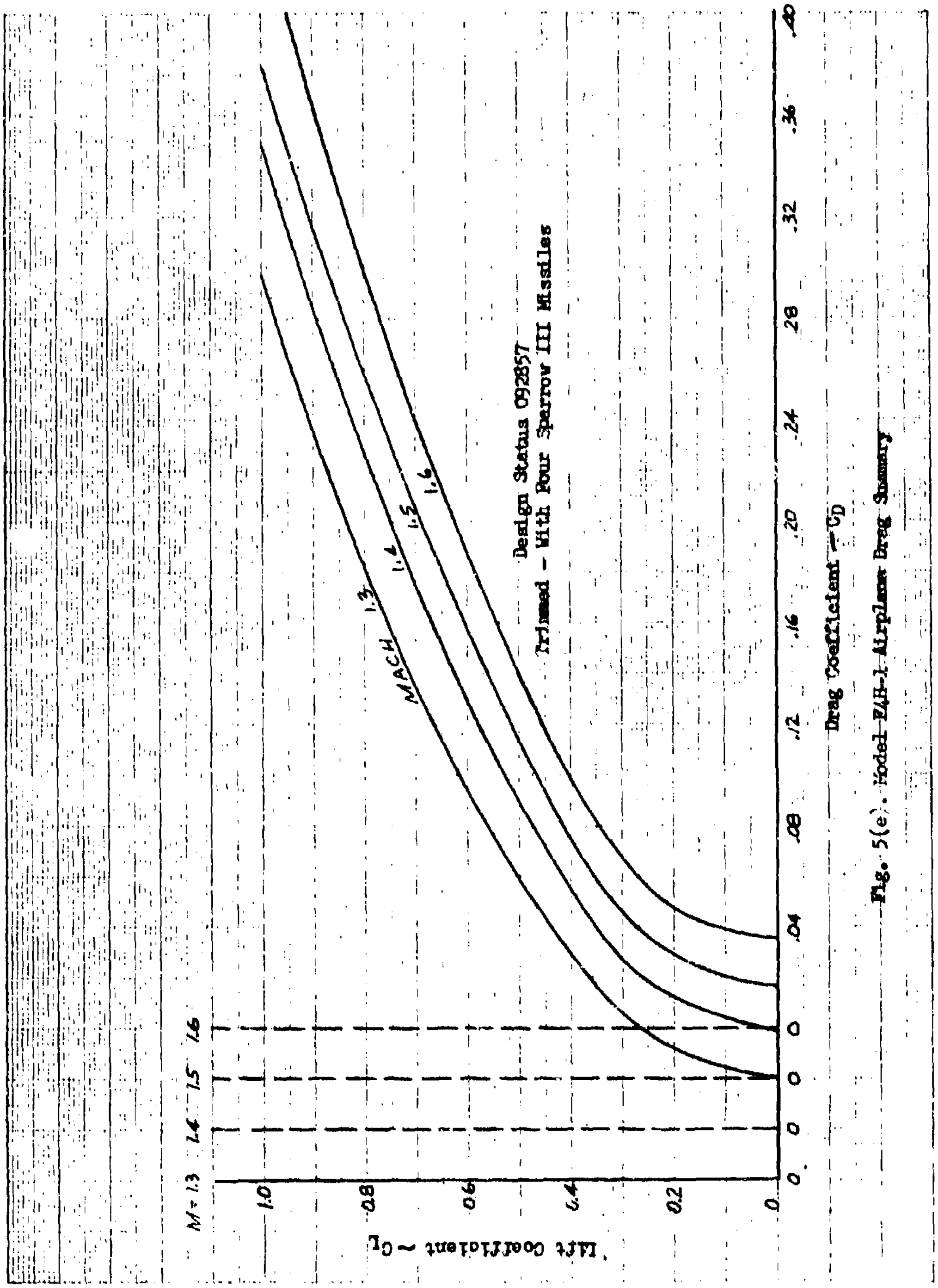


Fig. 5(e). Model F4H-1 Airplane Drag Summary

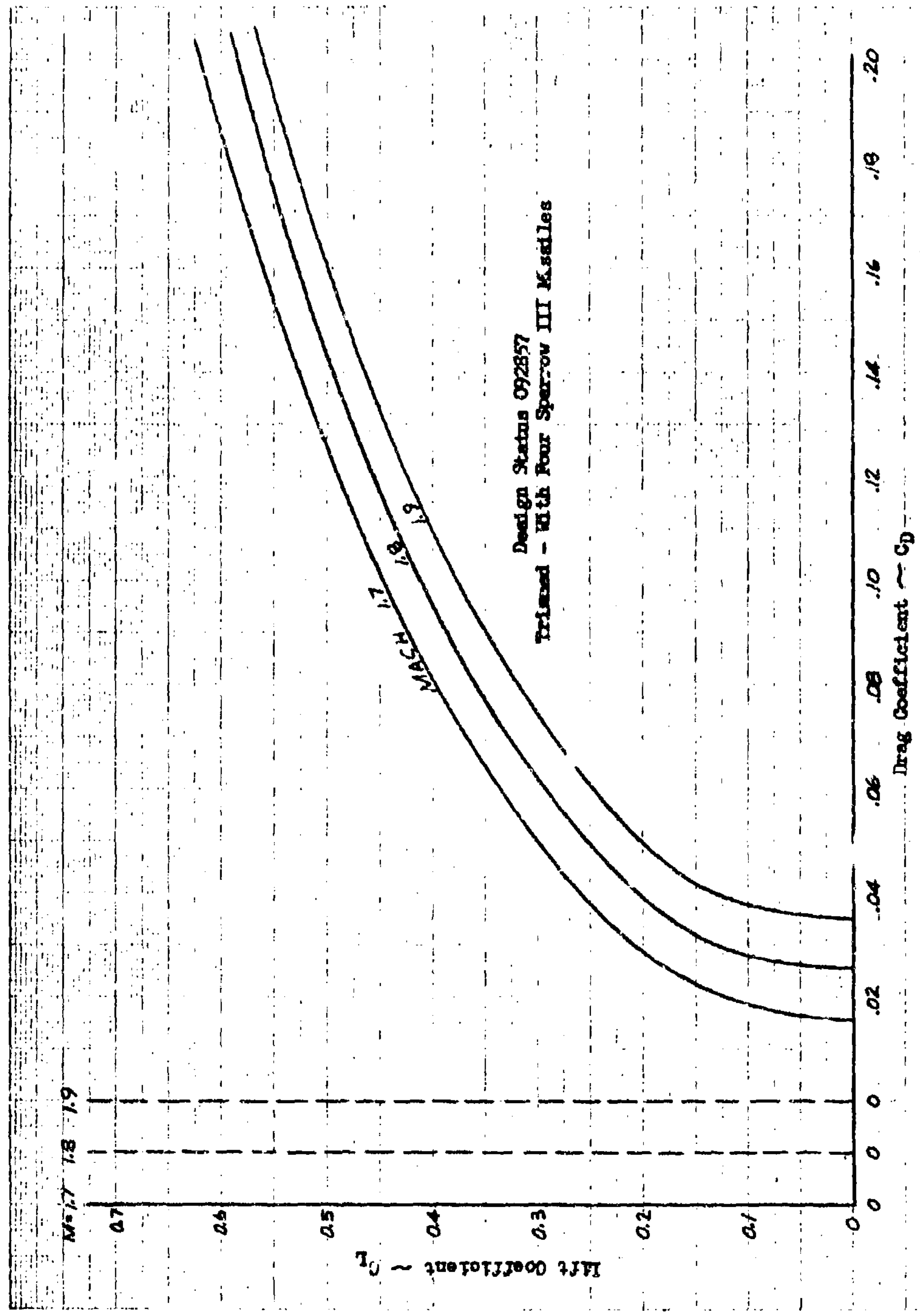


Fig. 5(f). Model F4H-1 Airplane Drag Survey

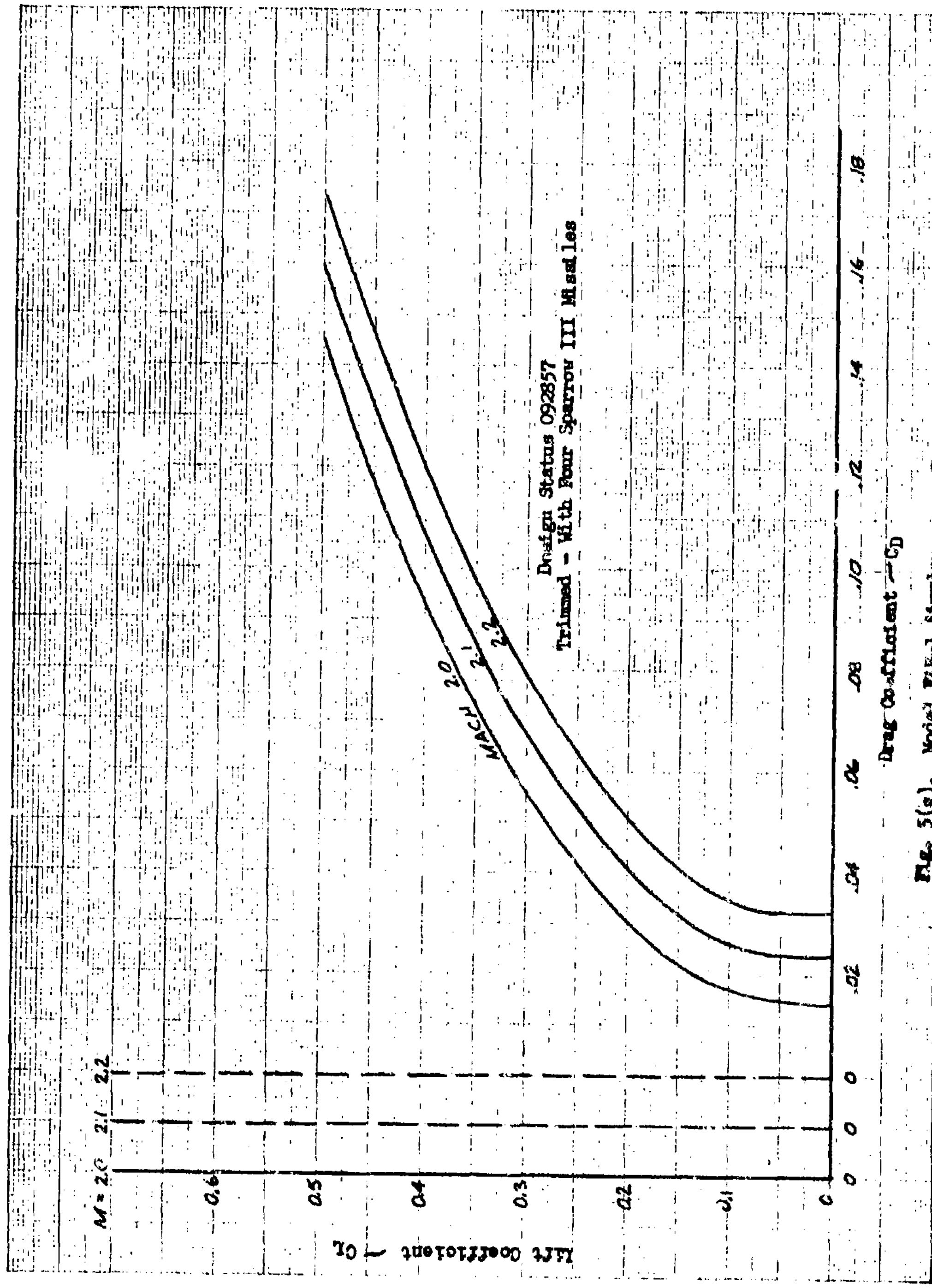


Fig. 5(g). Model F4H-1 Airplane Drag Summary

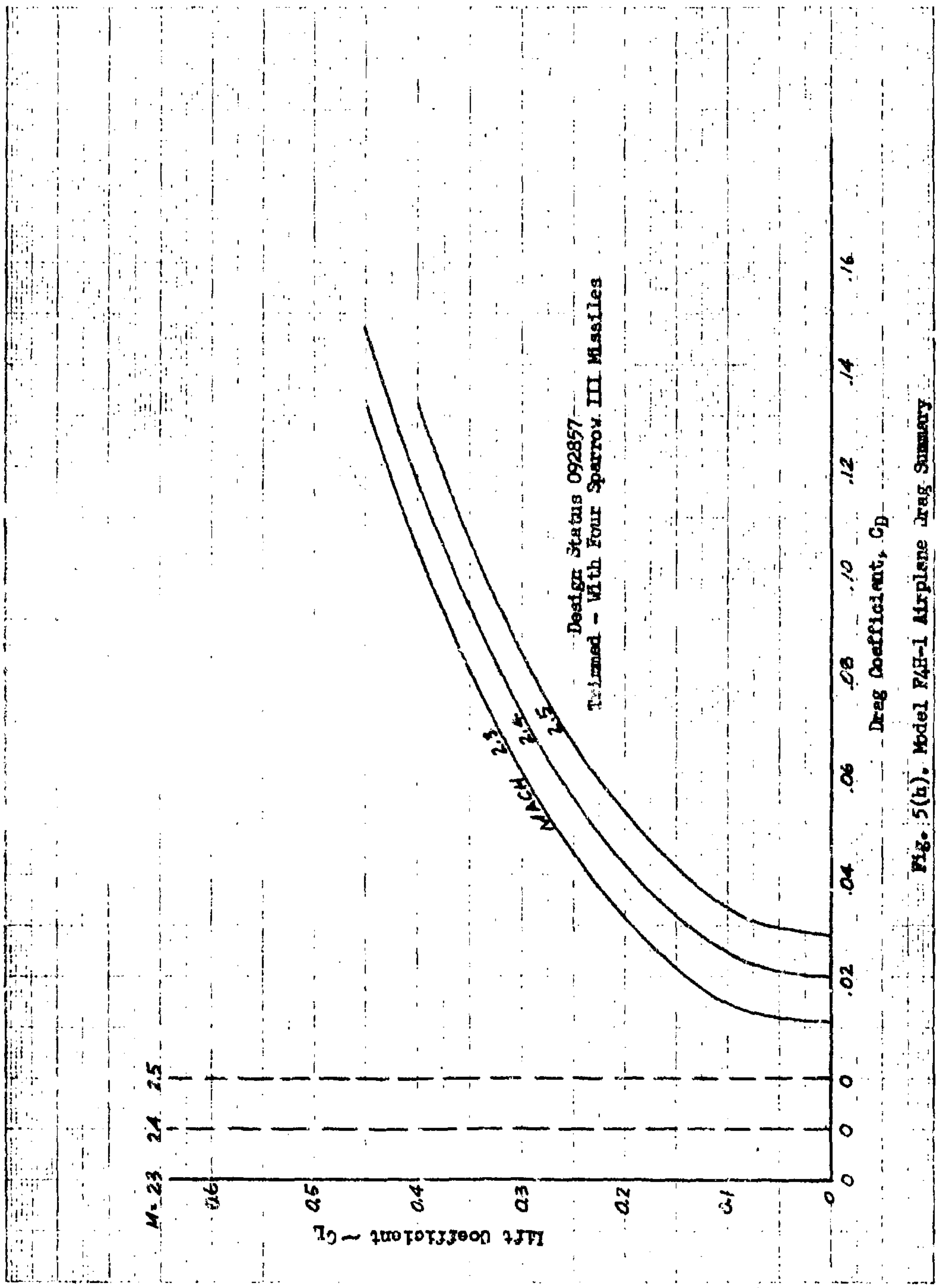


Fig. 5(h). Model F4H-1 Airplane Drag Summary

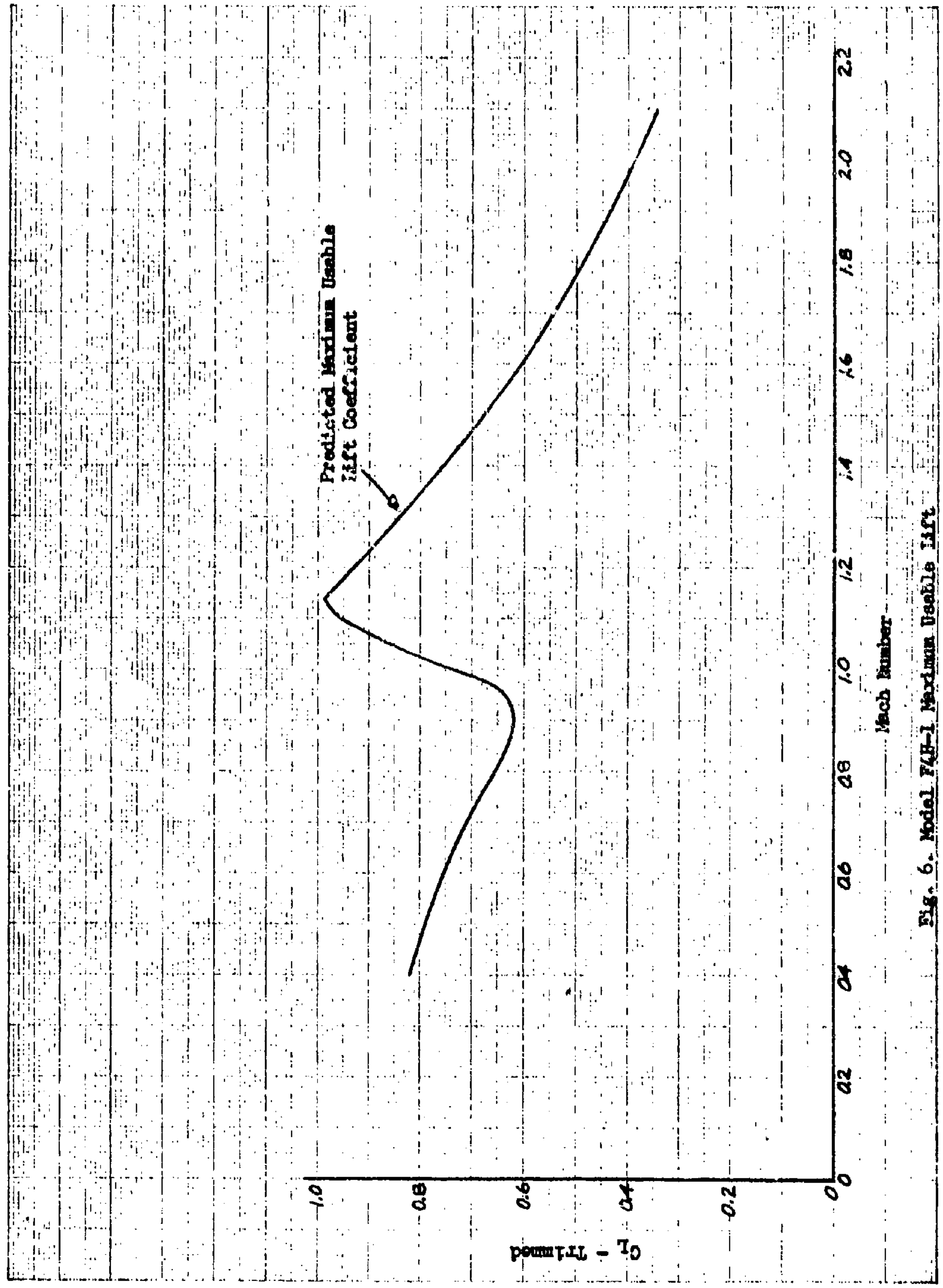


Fig. 6. Model F4H-1 Maximum Usable Lift

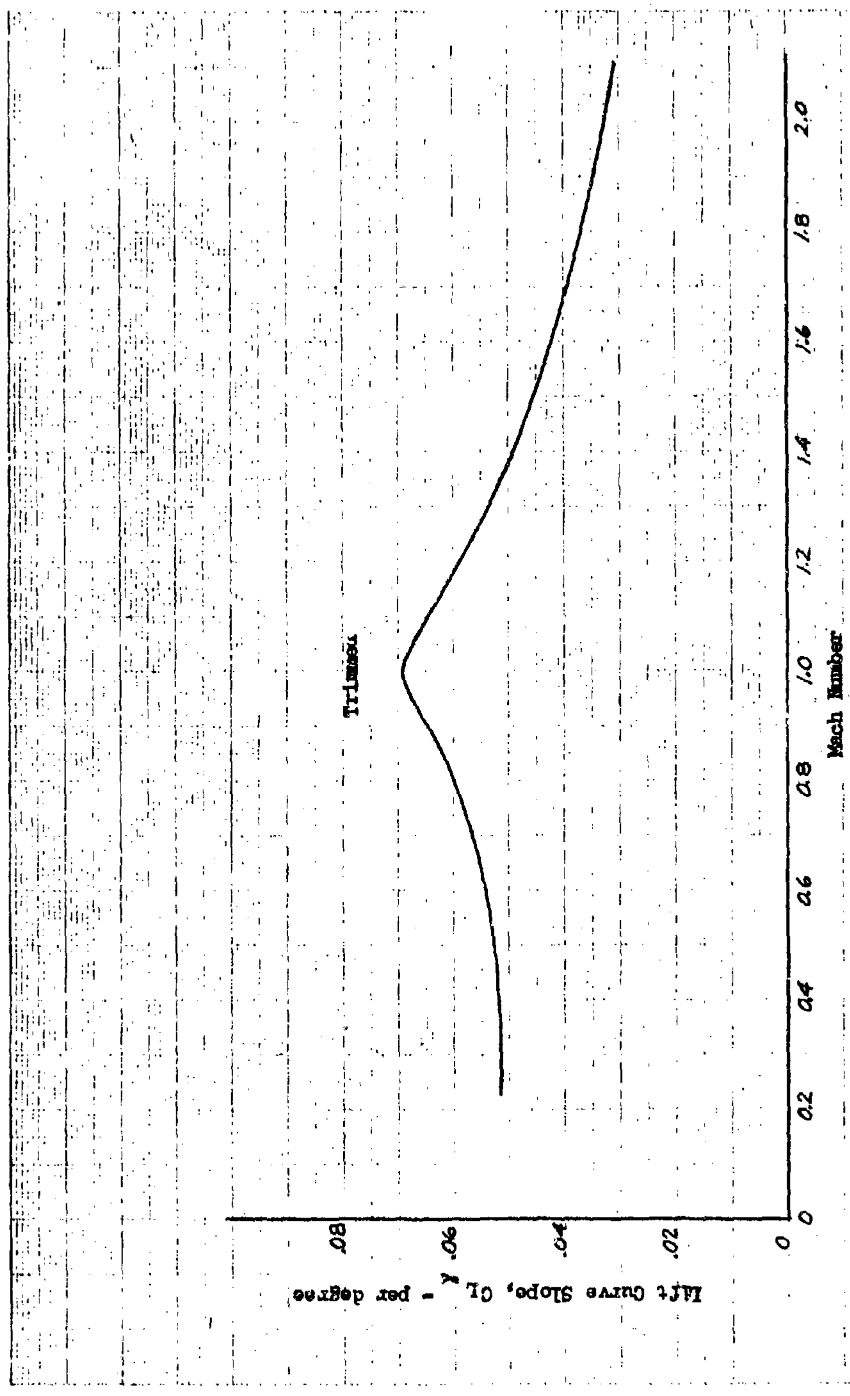


Fig. 7. Model F4H-1 Lift Curve Slope Variation with Mach Number

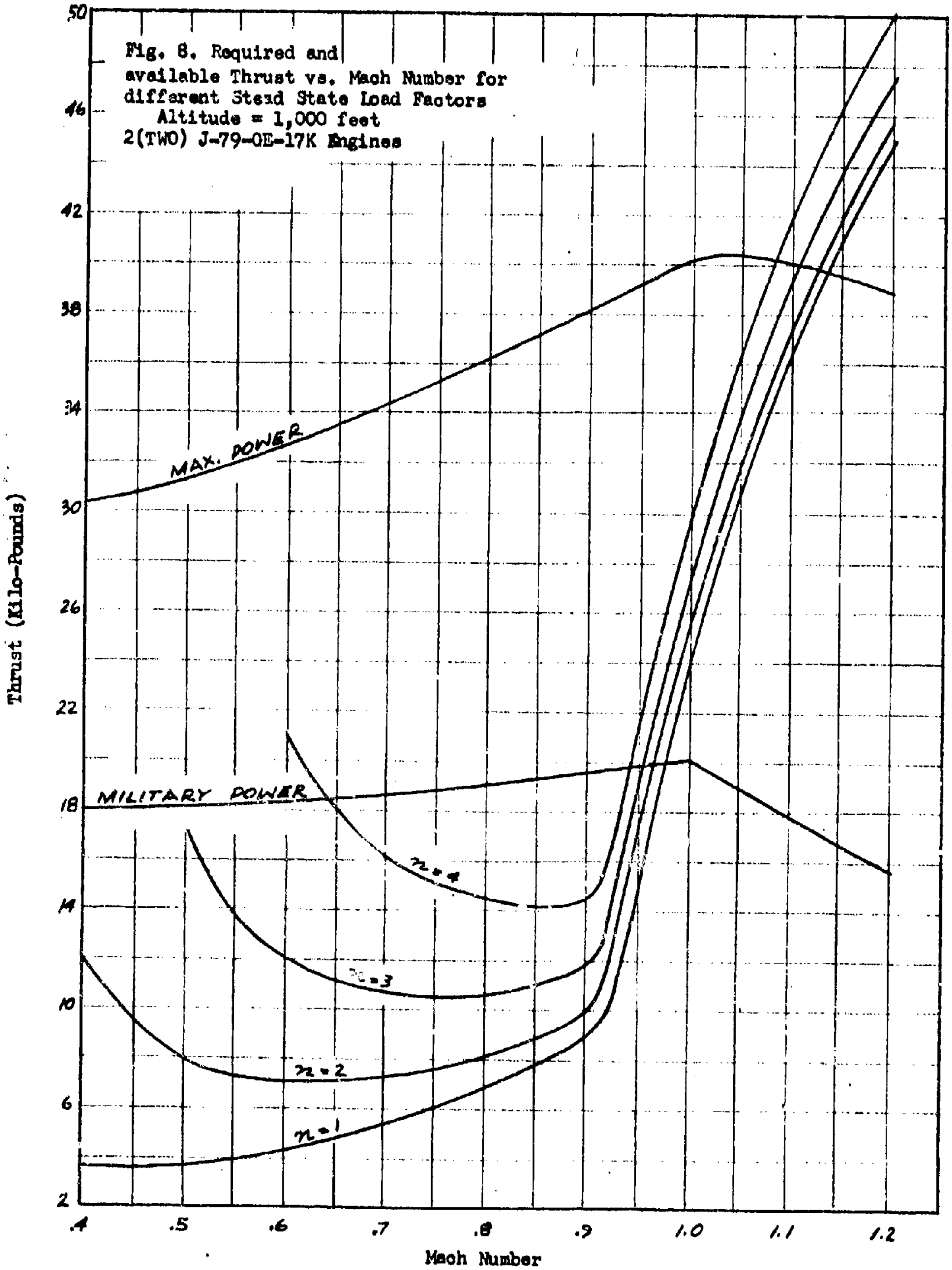
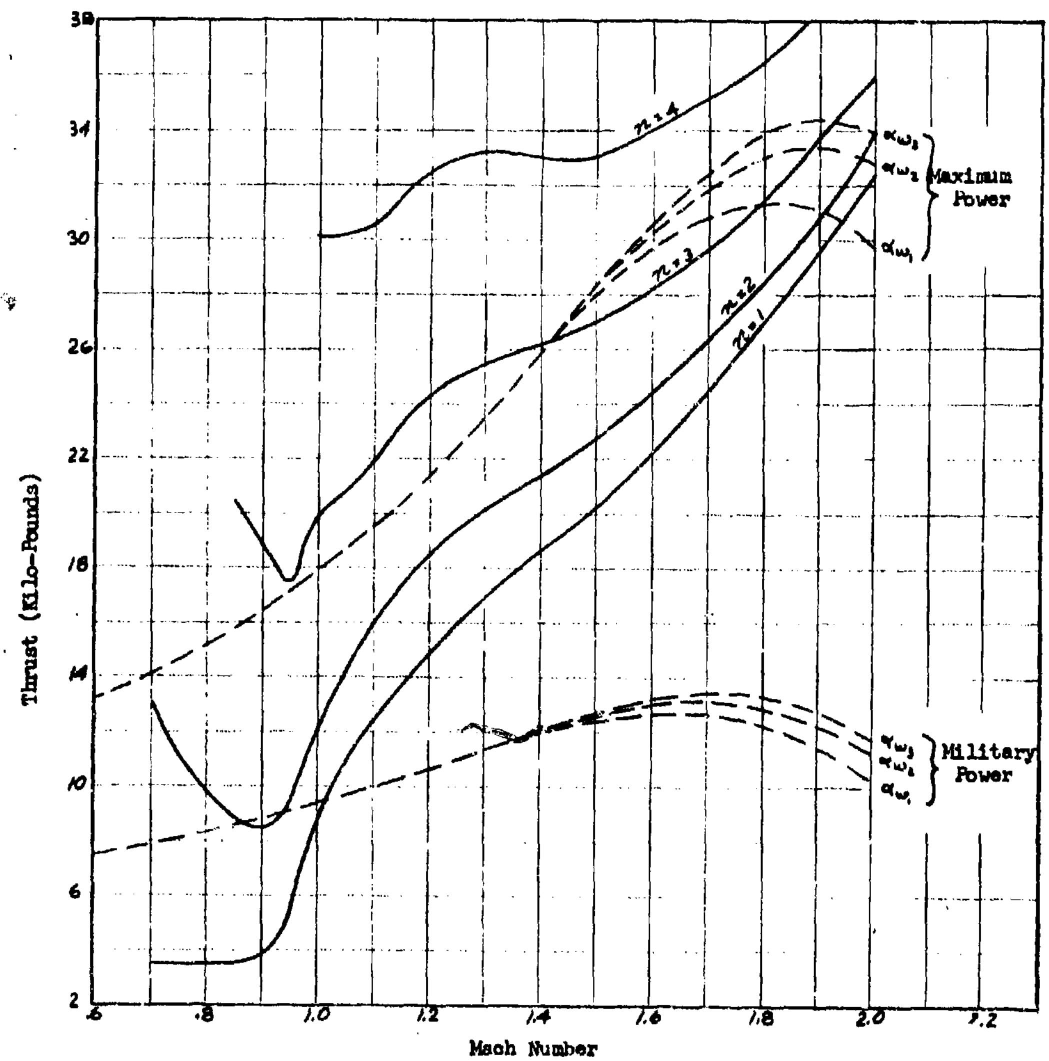


Fig. 8. Required and
available Thrust vs. Mach Number for
different Stead State Load Factors
Altitude = 1,000 feet
2(TWO) J-79-GE-17K Engines
Thrust (Kilo-Pounds)
Mach Number
MAX. POWER
MILITARY POWER
n = 4
n = 3
n = 2
n = 1
50
46
42
38
34
30
26
22
18
14
10
6
2
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2

Fig. 9. Required and Available Thrust vs. Mach Number for Different Steady State Load Factors
Altitude = 30,000'

Note: α_{w_1} - Airplane Wing Angle of Attack = 0° and 15°
α_{w_2} - Airplane Wing Angle of Attack = 3° and 11°
α_{w_3} - Airplane Wing Angle of Attack = 6°
2(TWO) J-79-GE-17K Engine



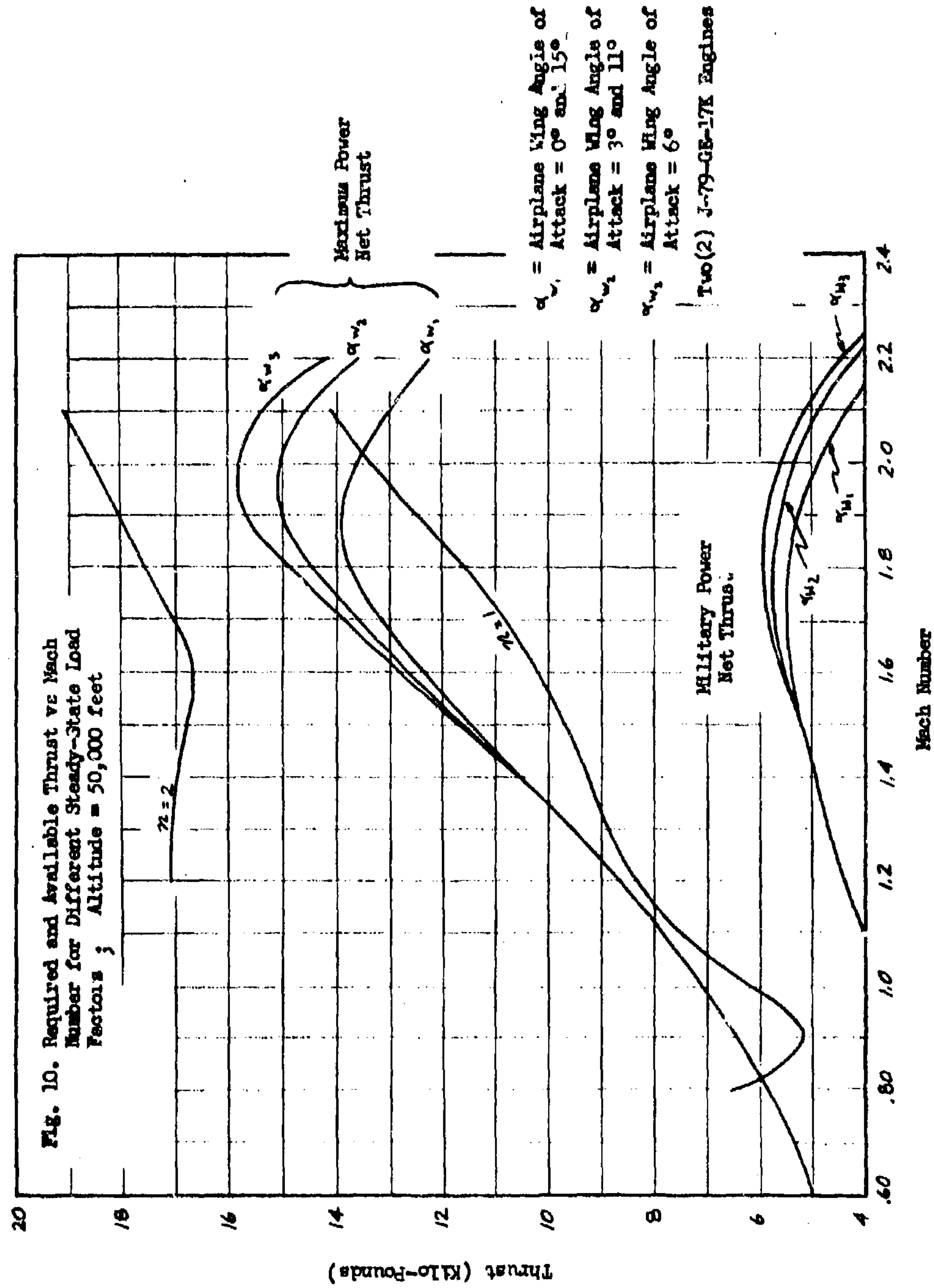


Fig. 10. Required and Available Thrust vs Mach Number for Different Steady-State Load Factors ; Altitude = 50,000 feet

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